SUBCOURSE EN5458

EDITION 6

FLEXIBLE PAVEMENT STRUCTURES

AIPD

READINESS/ PROFESSIONALISM THRU GROWTH

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

US ARMY ENGINEER

FLEXIBLE PAVEMENT STRUCTURES
SUBCOURSE EN5458

Nine Credit Hours

GENERAL

The Flexible Pavement Structures subcourse is designed to teach you design considerations of subgrade, base, and surface for road, airfield, and heliports in the theater of operation; and the design of flexible pavements for frost conditions. The subcourse is presented in three lessons, each corresponding to a terminal learning objective as indicated below.

Lesson 1: DESIGN CONSIDERATIONS FOR ROADS

TASK: Identify the steps used to design the flexible pavement structures for roads in the theater of operation.

CONDITIONS: Given this subcourse, an ACCP Examination Response Sheet, and a No. 2 pencil.

STANDARDS: Demonstrate the competency of the task skills and knowledge by responding correctly to 75% of the examination questions.

Lesson 2: DESIGN AN AIRFIELD FLEXIBLE PAVEMENT

TASK: Identify the steps used to design flexible pavement structures for airfields and heliports.

CONDITIONS: Given this subcourse, an ACCP Examination Response Sheet, and a No. 2 pencil.

STANDARDS: Demonstrate competency of the task skills and knowledge by responding correctly to 75% of the examination questions.

Lesson 3: DESIGN FOR FROST CONDITIONS

TASK: Identify the steps used to design flexible pavement structures for frost conditions.

CONDITIONS: Given this subcourse, an ACCP Examination Response Sheet, and a No. 2 pencil.

STANDARDS: Demonstrate competency of the task skills and knowledge by responding correctly to 75% of the examination questions.

***** IMPORTANT NOTICE *****

THE PASSING SCORE FOR ALL ACCP MATERIAL IS NOW 70%.

PLEASE DISREGARD ALL REFERENCES TO THE 75% REQUIREMENT.

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GRADING AND CERTIFICATION INSTRUCTIONS

INSTRUCTIONS TO THE STUDENT

This subcourse has a written performance-based, multiple-choice examination which covers the three lessons. In order to meet the objectives of this subcourse successfully, you must score a minimum of 70% on the examination. When you have completed the subcourse, fill out the Army Correspondence Course Program (ACCP) Examination Response Sheet with a No. 2 pencil and mail it to the Army Institute for Professional Development (IPD) in the envelope provided.

Nine credit hours will be awarded for successful completion of this subcourse.

INTRODUCTION

Modem warfare has created unprecedented requirements for mobility. There are ever increasing demands for soundly engineered and properly maintained roads and airfields. In a theater of operations, the rapid construction and maintenance of road nets and airfields must proceed in the face of tremendous difficulties. To meet his increasing responsibilities, the engineer must have a complete understanding of pavement materials, design considerations, and construction procedures.

This subcourse contains detailed information about the types and uses of flexible pavements; material estimation; design and construction procedures, and the types and uses of expedient paving surfacing.

Lesson 1
DESIGN CONSIDERATIONS FOR ROADS

TASK: Identify the steps used to design flexible pavement structures for roads in the theater of operations.

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by responding correctly to 75% of the examination questions related to the task for this lesson.

CREDIT HOURS: 3

REFERENCES

TM 5-330
TM 5-530
ST 5-330-8

Learning Event 1
FLEXIBLE PAVEMENTS AND ROADS
INTRODUCTION

Pavement (including the surface and underlying courses) is divided into two broad classifications or types – rigid and flexible. The term "rigid pavement" is applied when the wearing surface is constructed of portland cement concrete. Pavement constructed of concrete will possess considerable flexural strength which will permit it to act as a beam and allow it to bridge over minor irregularities which may occur in the base or subgrade upon which it rests, hence it is "rigid." All other pavement or bases are called "flexible."

In flexible pavements, the distortion or displacement occurring in the subgrade is reflected in the base course and on upward to the surface course. Thus the term "flexible" is used to denote the tendency of all courses in this type of structure to conform to the same shape under traffic. Flexible pavements are used almost exclusively in the theater of operations for road and airfield construction since they are adaptable to almost any situation and capabilities of a normal engineer troop unit.

This Learning Event will be concerned primarily with the design considerations.

Flexible Pavement Structure

A typical flexible pavement structure (Figure 1) illustrates the terms used in this subcourse when referring to various layers. All flexible pavement will not have every layer shown in Figure 1. For example a two layer structure consisting of only a compacted subgrade and a base course is a complete flexible pavement. The word "pavement" when used by itself refers to only the leveling, binder and surface courses, while flexible pavement refers to the entire pavement structure from the subgrade up.

The design of flexible pavement must be based on complete and thorough investigations of subgrade conditions, borrow area and sources of select materials, subbase and base materials. The Battalion Soils Section of the Combat Heavy Battalion will determine the California Bearing Ratio (CBR) and other soil properties of available materials and the subgrade. (Refer to Engineer Subcourse 5453, Soils Engineering, for more information on testing of soil.)

Distribution of Loads

A pavement composition, Figure 2, shows two typical sections of flexible pavement, one with a thick and one with a thin base course. In either case, the subgrade is the foundation which eventually carries any load applied at the surface. Airfields or roads usually must be leveled and shaped; consequently, the subgrade is defined as the natural soil which is compacted or treated to receive the base and wearing surface. The subbase and base are composed of higher quality material than the subgrade. This material may be imported or selected from the site.

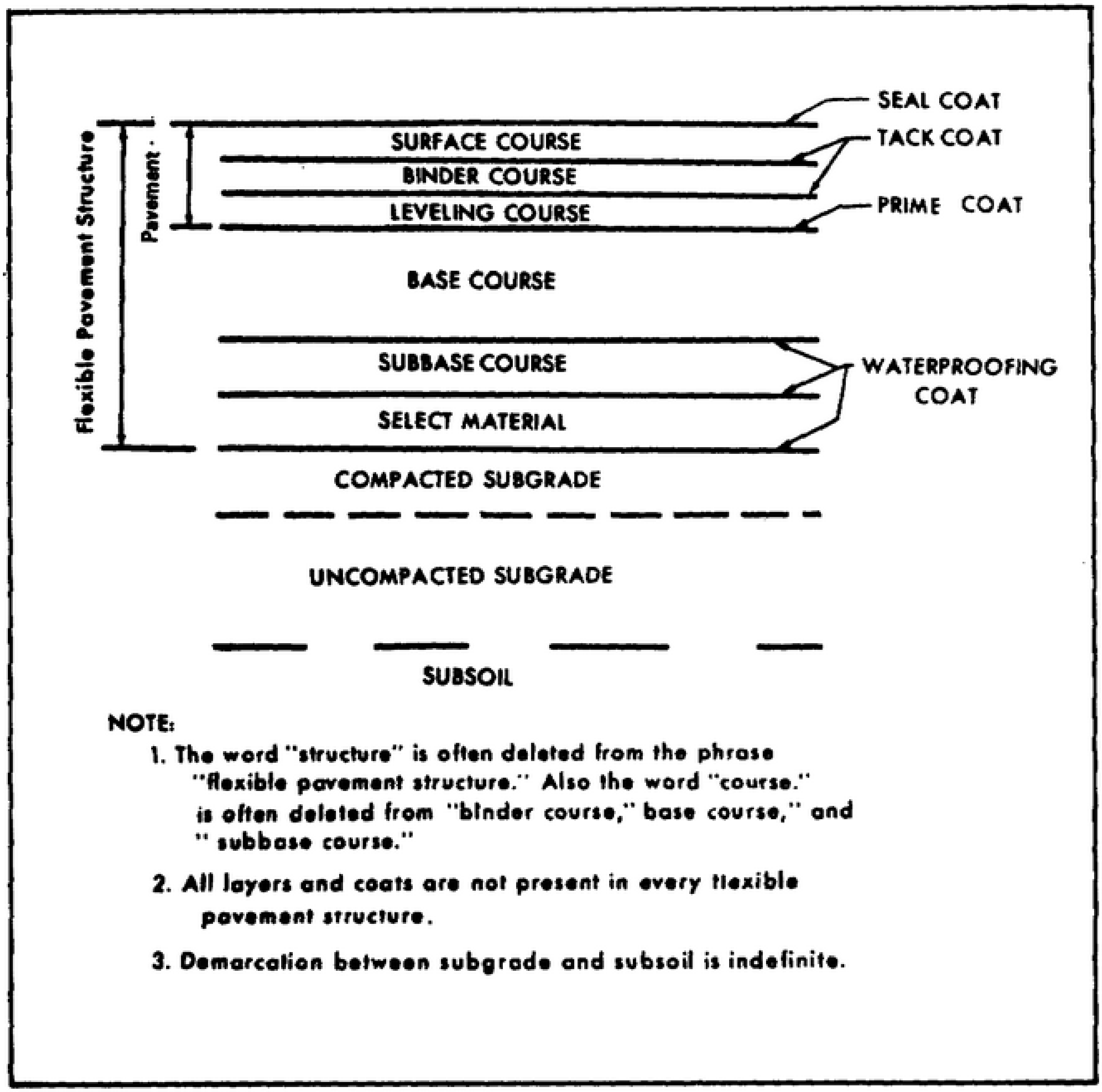

FIGURE 1. TYPICAL FLEXIBLE PAVEMENT.

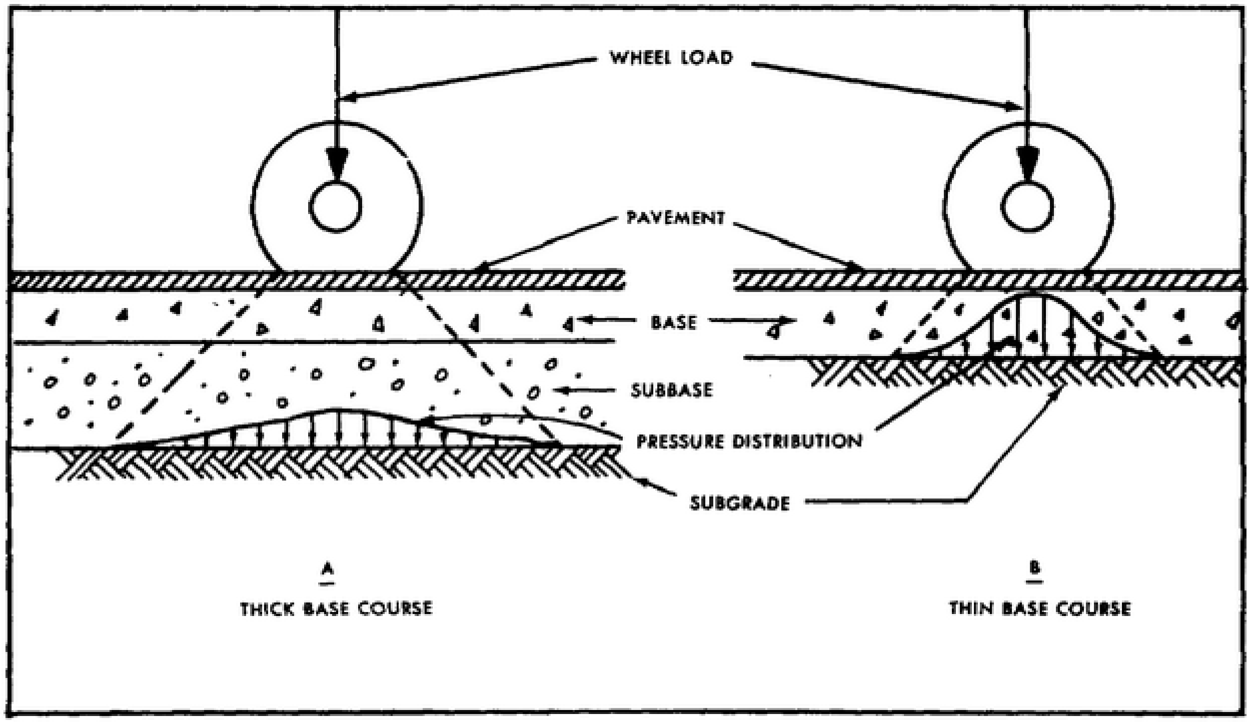

FIGURE 2. DISTRIBUTION OF PRESSURE UNDER SINGLE WHEEL LOADS

The design of flexible pavement is based on the principle that the magnitude of stress induced by wheel load decreases with depth below the surface. Therefore, the stresses induced by a wheel can be decreased by increasing the thickness of superimposed base and pavement. Figure 2 illustrates this point. In the diagram to the left, the base (including subbase) is thick. Therefore, the load at the subgrade is spread out over a wide area and the pressures are small. In the diagram to the right, the base is thin and the load at the subgrade is confined to smaller area, and the pressures are correspondingly higher. This pattern of decreasing stresses with increasing depth is the basis of conventional flexible pavement design in which subgrade materials of low bearing capacity are covered with thick flexible pavement structures. Thin flexible pavements are adequate for subgrade materials with high bearing capacities.

Effect of Tandem Axles and Tire Pressures

Tandem Axles: Figure 2 illustrates the distribution of pressure under a single wheel load. Tandem axles are beneficial in the case of flexible pavement having high subgrade strength and a thin base course because the stresses produced by the tires of tandem axles do not overlap appreciably at shallow depths (Figure 3, Plane A-A).

In the case of flexible pavement, with low subgrade strength and thick base course, the stresses produce overlap (Figure 3, Plane B-B) and less benefit is gained from the use of tandem axles. Criteria are given in this subcourse for designing and evaluating tandem axles for both roads and airfields.

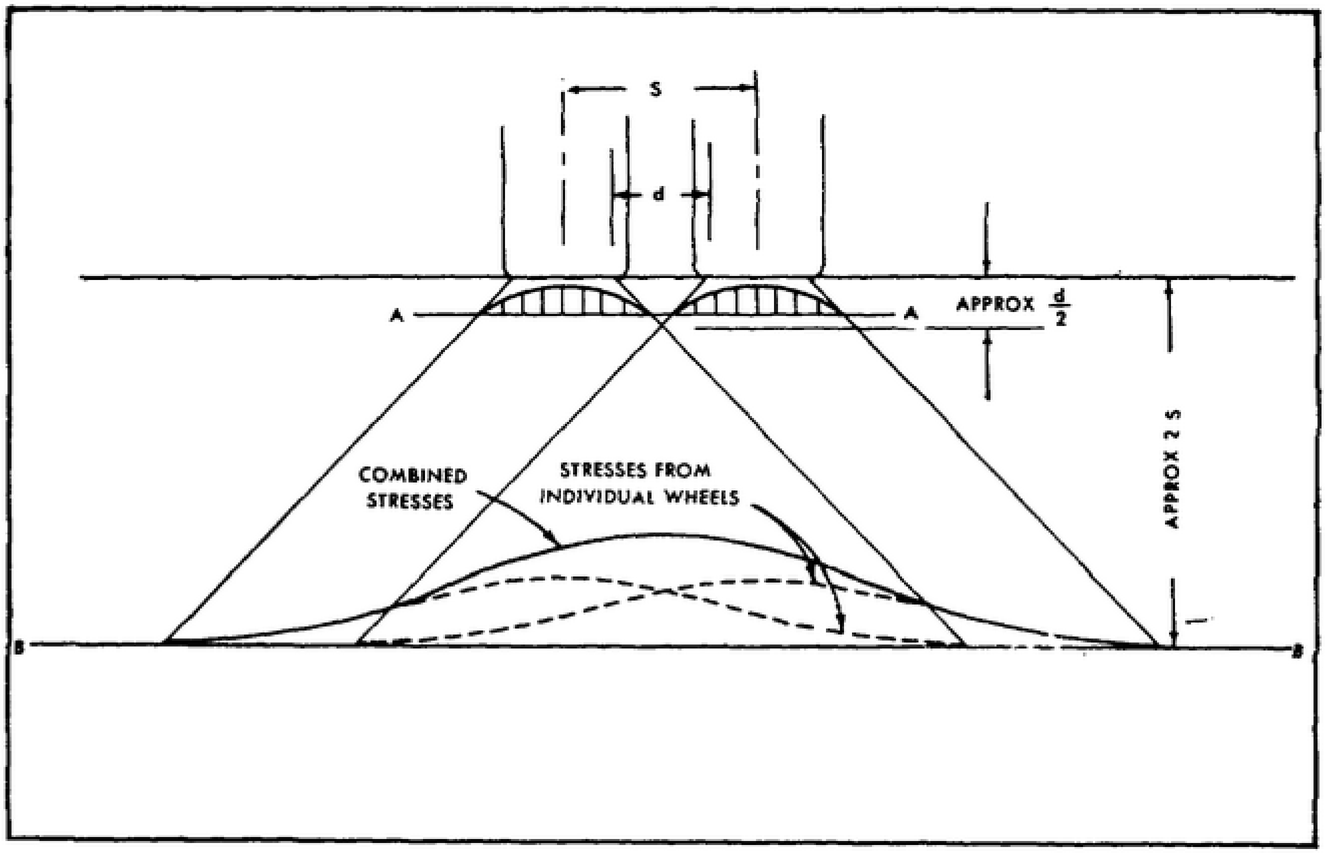

FIGURE 3. DISTRIBUTION OF PRESSURES PRODUCED BY MULTIPLE WHEEL ASSEMBLIES

Tire Pressure: The intensity of stress at a given point in a flexible pavement is directly affected by the tire contact area and the tire pressure. The major difference is stress intensities caused by variation in tire pressure. Occurring near the surface, the pavement and upper base course are most seriously affected by high tire pressure.

Learning Event 2
SUBGRADE, SUBBASE, AND BASE FACTORS

Subgrade Factors to be Considered

The information obtained from the exploration and tests previously referred to should be adequate to enable full consideration of all factor affecting the suitability of the subgrade and subsoil. The primary factors are as follows:

- General characteristics of the subgrade soil
- Depth to ledge rock
- Depth to water table
- Compaction that can be attained in the subgrade and the adequacy of the existing density in layers below the zone of compaction requirements
- CBR that the compacted subgrade, uncompacted subgrade, and subsoil will have under future conditions
- Presence of weak or soft layers in the subsoil
- Susceptibility to detrimental frost action

Grade Line

The investigation and tests previously described will result in classification of the subgrade and subsoil in accordance with the Unified Soil Classification System. Table 5 of EN 5453, Soils Engineering, lists the various soils in descending order of their desirability as subgrade soils. You should consider this information together with information on the depth to water table, depth to ledge rock, and the compaction and strength characteristics in locating the grade line of the top of the subgrade. Generally, this grade line should be established to obtain the best possible subgrade material consistent with the proper utilization of available materials; however, you must also consider economics of plans with construction.

Subgrade Compaction – Normal Cases

In general, compaction increases the strength of subgrade soils. The normal procedure is to specify compaction in accordance with requirements in Figure 4.

The problem is relatively simple to fill sections since all the layers will be subjected to construction processes and can be compacted during construction.

The problem is more difficult in cut sections. You must obtain compaction during construction to a depth where the natural density will resist densification under further traffic. It is recommended that in cut sections only the top 6 inches of subsoil be recompacted if required. Cohesionless soils (except silts) can often be compacted from the surface with heavy rollers or very heavy vibrating compactors. Cohesive soils (including silts) cannot be compacted in thick layers; therefore, it may be necessary to remove, process, and replace soil in cut areas in order to meet the compaction requirements as previously discussed. In addition, you should compare the natural densities occurring in the subsoil with the compaction requirements for the deeper depths to determine if compaction of the subsoil is necessary, or if the flexible pavement structure must be established so that these layers are deep enough that they will not be affected by loadings to be applied.

Compaction of cohesive materials, including those of relatively low plasticity showing little swell, should be accomplished at the optimum moisture content determined in the modified AASHO (CE 55) compaction test. This moisture content is generally slightly drier than the true optimum for field compaction using normal equipment. This difference has been recognized and accepted as a slight safety factor. Cohesionless, free-draining materials should be compacted at moisture contents approaching saturation.

Subgrade Compaction – Special Cases

Although compaction increases the strength of most soils, some soils decrease in stability when scarified, worked, and rolled. There are also some

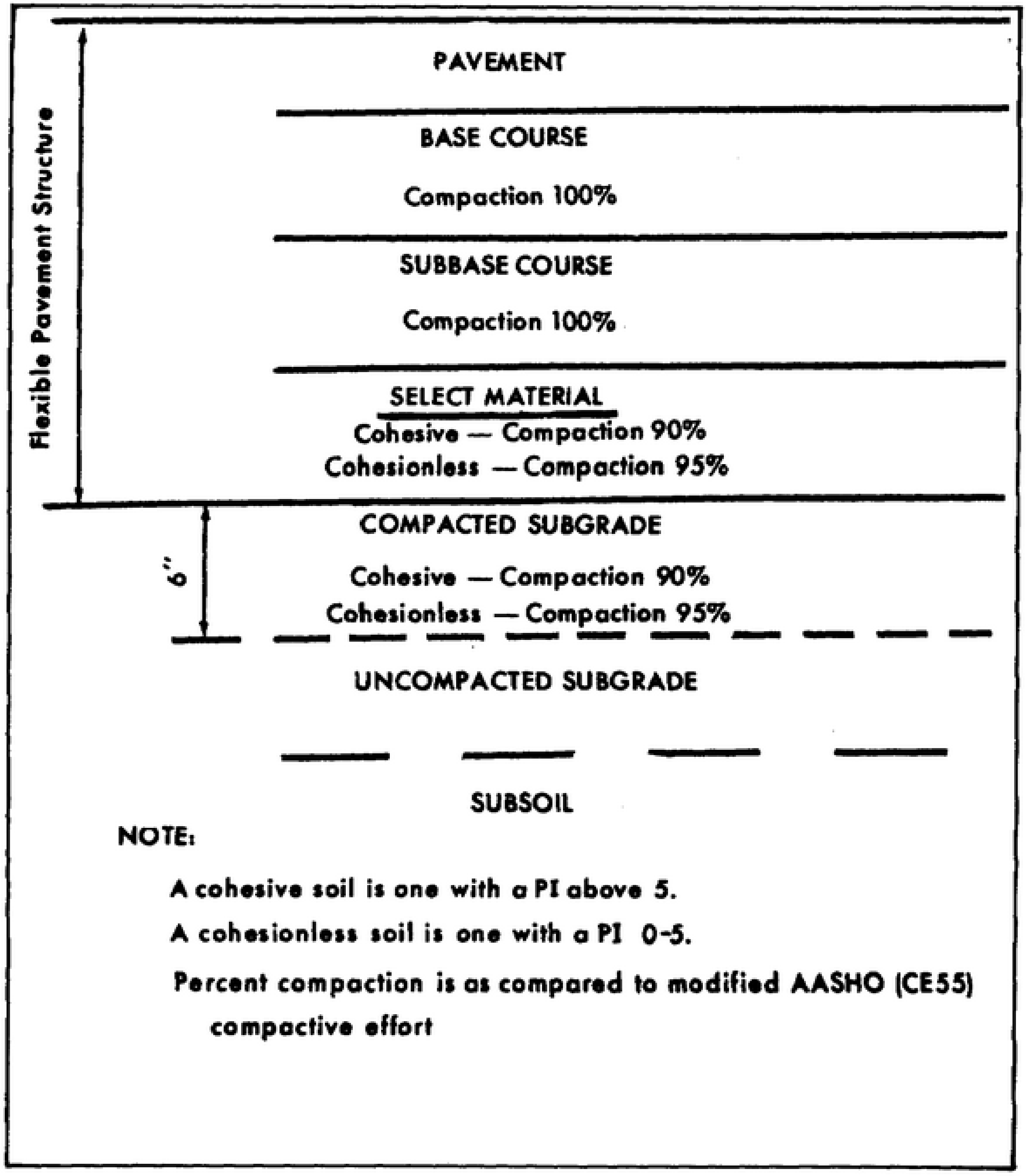

FIGURE 4. RECOMMENDED REQUIREMENTS FOR REAR AREA FULL OPERATIONAL AND MINIMUM OPERATIONAL AIRFIELDS

soils that shrink excessively during dry period and expand excessively when allowed to absorb moisture. When these soils are encountered, special treatment Is required. General descriptions of the soils in which these conditions may occur and suggested methods of treatment are outlined below:

Remolded Clay. The types of clays that show a decrease in strength when remolded are generally in the CH and OH groups. They are clays that have been consolidated to a very high degree, either under an overburden load or by alternate cycles of wetting-and-drying, or that have by other means developed a definite structure. They have a high strength in the undisturbed state. Scarifying, reworking, and rolling these soils in cut areas may produce a lower bearing value than that of the undisturbed soils. When such clay soils are encountered, obtain the bearing values for both the undisturbed soil and the soil removed; compact them to the design density at the design moisture content and adjust them to the future moisture content conditions. If the undisturbed value is the higher, do not attempt any compaction and conduct construction operations to produce the least possible disturbance of the soil. Since compaction cannot be effected in these cases, the total thickness design above the subgrade may be governed by the required depth of compaction rather than the CBR method.

Remolded Silts. Experience has shown that some deposits of silt, very fine sand, and rock flour (predominantly in classifications ML and SC) when compacted in the presence of a high water table will pump water to the surface and become "quaky" or "spongy" with a loss of practically all bearing value. The condition can also develop in most silts and poorly draining, very fine sands if these materials are compacted at a high moisture content, because the compaction reduces the air voids so that the available water fills practically all the void space. Therefore, it is difficult to obtain the desired densities in these silts and very fine sands at moisture contents greater than optimum. Also during compaction of the base, the water from a wet, spongy silt subgrade will often enter the subbase and base with detrimental effects. The bearing value of these silts and very fine sands is reasonably good if they can be compacted at the proper moisture content. Drying is not difficult if the source of water can be removed, since the soils are usually friable and can be scarified readily. If the soils can be dried, apply normal compaction requirements. However, removing the source of water is often very difficult and in some cases impossible in the allotted construction period. In cases of high water table, drying is usually not satisfactory until the water table is lowered, as recompacting operations will again cause water to be pumped to the surface. Local areas of this nature are usually treated satisfactorily by replacing the soil with subbase and base materials or with a dry soil that is not critical to water.

In cases where drainage is not feasible and a high water table cannot be lowered, or in cases where such soils become saturated from other sources than high water table and cannot be dried out (as in necessary construction during wet seasons), the subgrade should not be disturbed. Additional thicknesses of base and pavement should be used to insure that the subgrade will not be overstressed or compacted during subsequent traffic. Anticipate pumping and detrimental actions previously described whenever silts or very fine sand subgrade are accompanied by a high water table. This pumping action limits the ability to obtain compaction in the immediately overlying material which must be considered in the design.

Treatment of soils with expansive characteristics. Soils with expansive characteristics occur and give the most trouble in certain areas of the world where climatic conditions are conducive to significant changes in moisture content of the subgrade during different seasons of the year. Such soils can also give trouble in any region where construction is accomplished in a dry season and the soils absorb moisture during a subsequent wet season. If highly compacted, these soils will swell and produce uplift pressures of considerable intensity if the moisture content of the soil increases after compaction. This action may result in differential heaving of flexible pavements that is unacceptable. Where the amount of swell is less than about 3 percent, special considerations will not normally be needed.

A common method of treating a subgrade with expansive characteristics is to compact it as a moisture content and to a unit weight that will minimize expansion. The proper moisture content and unit weight for compaction control of a soil with marked expansion characteristics are not necessarily the optimum moisture content and unit weight determined by the modified AASHO (CE 55) test, but may be determined from a study of the relationships between moisture content, unit weight, percentage of swell, and CBR for a given soil, as determined by the CBR test. A combination of moisture, density, CBR, and swell which will give the greatest CBR and density consistent with an acceptable amount of swell must be selected. The CBR and density values so selected are those which must be considered in the design of overlying layer thickness.

Field control of the moisture content must be carefully exercised since if the soil is too dry when compacted, the expansion will increase; and if too wet, low unit weight will be obtained and the soil will shrink during a dry period and then expand during a wet period. Special solutions to the problem of swelling soils are sometimes possible and should not be overlooked where pertinent. For instance, where climate is suitable, it may be possible to place a permeable layer (aquifer) over a swelling soil and limit or prevent drainage therefrom. Moisture buildup in this layer maintains the soil in a stable, swelled condition. Designs must, of course, be based on the swelled CBR and density values of such a material when so treated.

Selection of Subgrade and Subsoil Design CBR Values

The CBR test described in TM 5-530 and Engineer Subcourse 5453, Soils Engineering, includes procedures for making tests on samples compacted in test molds to the design density and soaked 4 days, for making in-place CBR tests, and for making tests on undisturbed samples. These tests are used to estimate the CBR that will develop in the prototype structure. Where the design CBR is above 20, the subgrade must meet the requirements for subbases.

Subgrade Stabilization

Subgrades can be stabilized by the addition of granular materials or chemicals as admixtures. Consider stabilization with admixtures only when economical. When granular materials are used, give the stabilized layer a CBR rating as a subbase material, provided the admixed material meets the requirements of subbases, as given in selection of design CBR for select material and subbases. Otherwise, treat the stabilized layer as a layer of select material. Layers stabilized with portland cement or bituminous materials in proper quantities to produce good quality soil cement or bituminous stabilization shall be rated as a subbase with a CBR of 50. The surface of sand subgrades is often stabilized with bituminous materials or coarse cohesionless granular materials to form a "working flour." The treated layer is generally 4 inches or less in thickness. It should be assigned the same CBR as the underlying layer. Do not use clay or other plastic soils or highly organic soils (sometimes locally termed "muck") to stabilize sand subgrades.

TABLE 1. IN-PLACE STABILIZATION OF SUBGRADE SOILS

Stabilizing Agent	Soils	Objective	Amount Stabilizer Required	Evaluation	Sequence
Portland Cement	Fine grained soils with a PI[1] < 20, coarse-grained soils with amount passing the No. 4 sieve >45 percent	Provide a water resistant working platform, improve strength	3 to 12 percent	Should provide a compressive strength of 200 psi in seven days	Pulverize, moisten, mix, compact, seal, cure
Lime	Coarse & fine grained soils with a PI > 12	Provide a water-resistant working platform, improve strength	3 to 8 percent	Should provide a compressive strength of 50 psi in 28 days	Pulverize to 2-in. particles, moisten, mix, cure, repulverize; compact, seal. Lime may be added dry or mixed with water as slurry
Bitumen	Coarse grained soils with PI<10 and amount passing the No. 200 sieve$<$ 30 percent	Coat soil grains to provide a cohesive water-resistant working platform, improve strength	3 to 8 percent	Provide a firm, bonded mixture	Pulverize, mix, compact
Lime, Portland Cement	Coarse & fine grained soils (see above)	Reduce plasticity index, control swell, and improve strength	Lime: 1 to 2 percent Portland Cement: 3 to 5 percent	Test for improvement desired	Pulverize, moisten, add lime, mix, add Portland cement, mix, seal, cure

[1]PI – Plasticity index.

Stabilization of Soils with Portland Cement

Portland cement stabilization is applicable to granular soils and to low plasticity clays that can be thoroughly pulverized. In general, soils to be stabilized with cement should have a plasticity index of less than 20 and a minimum of 45 percent passing the #4 sieve, to permit proper mixing, as indicated

in Table 1. However, portland cement may be considered for heavier clays if the clay is first treated with lime or fly ash.

Relatively small amounts of portland cement may be used to modify the plasticity index and swell characteristics of the soil. Test for desired improvement by Atterberg limits and swell tests.

Stabilization with Lime

Fine grained soils, clays and silts with a plasticity index of 12 or greater with at least 12 percent of the material passing a #200 sieve are considered potentially capable of being stabilized by lime. However, certain clay minerals will behave differently in the presence of lime making laboratory tests necessary to determine the effectiveness of the lime treatment. The plasticity index and swell potential of the soil may be reduced by addition of one to six percent hydrated lime by weight. If quicklime is used, the amount required may be reduced by 25 percent. It should be noted, however, that quicklime is highly caustic and hazardous to handle. Use Atterberg limits and swell tests to determine the amount of lime required.

Lime may also be used to dry out wet soils. Quicklime is especially advantageous for this purpose as heat of hydration is generated on exposure to moisture.

The use of lime requires adequate equipment and special construction practices which must be followed very carefully if uniform results are to be obtained. Lime is normally mixed with the pulverized soil and then allowed to "cure" or mellow for from three to 14 days prior to repulverizing, mixing, and compaction. For highly plastic soils it may be more advantageous to apply half the lime during the initial mixing and the balance during final mixing.

Stabilization with Bitumen

In general, soil with a plasticity index of less than 10 with not more than 30 percent passing the #200 sieve can be stabilized with liquid bitumen or emulsion. The tendency in recent years has been to use emulsions in preference to liquid asphalts for mixed-in-place stabilization.

The bitumen content should be sufficient to provide a firm, stable foundation for operation of construction equipment. You can obtain preliminary estimates of the percent of bituminous materials required from the following:

Asphalt Cutback

For liquid asphalt use the following equation:

$$P = 0.02(a) + 0.07(b) + 0.15(c) + 0.02(d)$$

where

- p = percent of residual asphalt by weight of dry aggregate
- a = percent of mineral aggregate retained on #50 sieve
- b = percent of mineral aggregate passing #50 sieve and retained on #100 sieve
- c = percent of mineral aggregate passing #100 sieve and retained on #200 sieve
- d = percent of mineral aggregate passing #200 sieve

It should be noted that this equation provides only initial guidance for selection of bitumen content. Laboratory tests are required to determine a design bitumen content. Further adjustments in bitumen may be necessary in the field.

Asphalt Emulsion

Use Table 2 for an estimate of the emulsified asphalt requirements.

In-place mixing of the soils and stabilizing agent is permissible; however, it should be recognized that plant mixing will produce a more uniform product. Although the soil strength is upgraded, no reduction in the pavement thickness is normally permitted. However, should the stabilized soils meet the requirements for the subbase material, and exceed four inches in thickness, then the equivalency factor may be applied.

TABLE 2. EMULSIFIED ASPHALT REQUIREMENTS FOR SUBGRADE STABILIZATION

Percent Passing No. 200 Sieve	Pounds of Emulsified Asphalt per 100 pounds of Dry Soil When Percent Passing No. 10 Sieve is –					
	<50	60	70	80	90	100
0	6.0	6.3	6.5	6.7	7.0	7.2
2	6.3	6.5	6.7	7.0	7.2	7.5
4	6.5	6.7	7.0	7.2	7.5	7.7
6	6.7	7.0	7.2	7.5	7.7	7.9
8	7.0	7.2	7.5	7.7	7.9	8.2
10	7.2	7.5	7.7	7.9	8.2	8.4
12	7.5	7.7	7.9	8.2	8.4	8.6
14	7.2	7.5	7.7	7.9	8.2	8.4
16	7.0	7.2	7.5	7.7	7.9	8.2
18	6.7	7.0	7.2	7.5	7.7	7.9
20	6.5	6.7	7.0	7.2	7.5	7.7
22	6.3	6.5	6.7	7.0	7.2	7.5
24	6.0	6.3	6.5	6.7	7.0	7.2
25	6.2	6.4	6.6	6.9	7.1	7.3

Subbase Factors to be Considered

It is common practice in flexible pavement design to use locally available or other relatively cheap materials between the subgrade and base course for economy. Those layers are designated, in this manual, as select materials or subbases. Those with design CBR values of 20 are arbitrarily called select materials, while those with CBR values of 20 and above are called subbases. Minimum thicknesses of pavement and base have been established to eliminate the need for subbases with design CBR values above 50. Where the design CBR value of the subgrade without processing is in the range of 20 to 50, select materials and subbases may not be needed. However, the subgrade cannot be assigned design CBR values of 20 or higher unless it meets the gradation and plasticity requirements for subbases. In some cases, where subgrade materials meet plasticity requirements but are deficient in grading requirements, it may be possible to treat an existing subgrade by blending in stone, limerock, sand, etc., to produce an acceptable subbase; however, it is emphasized that "blending in" cohesionless materials to lower the plasticity index will not be allowed in any case.

Materials for Subbases

The investigations referred to previously will be used to determine the location and characteristics, respectively, of suitable soils for select material and subbase construction.

Select material. Select materials will normally be locally available coarsegrained soils (prefix G or S), although fine-grained soils in the ML and CL groups may be used in certain cases. Limerock, coral, shell, ashes, cinders, caliche, disintegrated granite, and other such materials should be considered when they are economical. Recommended plasticity requirements are listed in selection of design CBR for select materials and subbases. These are suggested to insure a material that can be processed readily. Materials not meeting these requirements may be considered where it can be shown that they can be processed readily. A minimum size of 3 inches is suggested to aid in meeting grades.

Subbase materials. Subbase materials may consist of naturally occurring coarse-grained soils or blended and processed soils. You may use materials such as limerock, coral, shell, ashes, cinders, caliche, and disintegrated granite as subbases when they meet the requirements described in selection of Design CBR for select materials and subbases. As noted in the preceding paragraph, the existing subgrade may meet the requirement for a subbase course or it may be possible to treat the existing subgrade to produce a subbase. Also, as noted, admixing native or processed materials will be done only when the subgrade unmixed meets the liquid limit and plasticity index requirements for subbases, because it has been found by experience that "cutting" plasticity in this way does not work out satisfactorily. Material stabilized with commercial admixes may be economical as subbases in certain instances. Portland cement, cutback asphalt, emulsified asphalt, and tar are commonly employed for this purpose. Also, it may be possible to decrease the plasticity in some materials by use of lime or portland cement sufficiently to make them suitable as subbases.

Compaction of Select Materials and Subbases

These materials can be processed and compacted with normal procedures. Compaction should be specified in accordance with the criteria described in Figure 4.

Selection of Design CBR for Select Material and Subbase

Tests are usually made on remolded samples; however, where existing similar construction is available, CBR tests should be made in-place on material when it has attained its maximum expected water content or on undisturbed soaked samples. The procedures for selecting test values described for subgrades apply to select materials and subbases. The CBR tests are supplemented by the gradation and Atterberg limits requirements for subbases as indicated in Table 3. Suggested limits for select materials are also indicated. In addition to the requirements shown in the table, the material must also show in the laboratory tests a CBR equal to or higher than the CBR assigned to the material for design purposes. Cases may occur in which certain natural materials that do not meet the gradation requirements may develop satisfactory CBR values in the prototype. Exceptions to the gradation requirements are permissible when supported by adequate in-place CBR tests on construction that has been in service for several years. The CBR test is not applicable for use in evaluating materials stabilized with chemical admixtures, and they must be rated by judgment in terms of an equivalent CBR. Ratings as high as 50 can be assigned these materials when proper construction procedures are followed.

Base Course Factor to be Considered

The purpose of a base course or courses is to distribute the induced stresses from the wheel load so that they will not exceed the strength of the subgrade. Figure 5 shows an idealized representation of the distribution of stress

through two base courses. When the subgrade strength is low, the stress must be reduced to a low value and a substantial thickness of base is needed. Where the subgrade strength is higher, a lesser thickness will provide adequate distribution. Since the stresses in the base course are always higher than in the subgrade (Figure 5), it stands to reason that the base course must have higher strength. Similarly, where two or more different types of base courses are used, the better quality material is placed on top.

TABLE 3. RECOMMENDED MAXIMUM PERMISSIBLE VALUES OF GRADATION AND ATTERBERG LIMIT REQUIREMENTS IN SUBBASES AND SELECT MATERIALS

Material	Maximum design CBR		Size inches		Gradation requirements % passing				Atterberg limits			
					No. 10		No. 200		LL		PI	
	Airfields	Roads	Air-fields	Roads	Air-fields	Roads	Air-fields	Roads	Air-fields	Roads	Air-fields	Roads
Subbase	50	50	3	2	50	50	15	15	25	25	5	5
Subbase	40	40	3	2	80	80	15	15	25	25	5	5
Subbase	30	30	3	2	100	100	15	15	25	25	5	5
Select Material	Below 20	20	3	3	-----	-----	25	-----	35	35	12	12

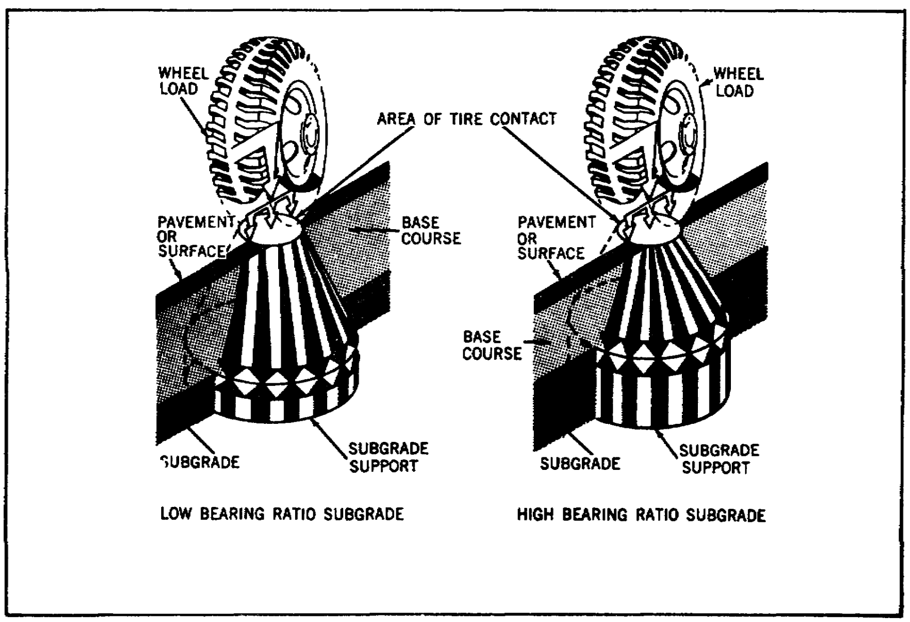

FIGURE 5. DISTRIBUTION OF STRESS IN BASE COURSES AND EFFECTS OF SUBGRADE STRENGTH ON BASE-COURSE THICKNESS

Base-Course Requirements

Careful attention should be given to the selection of materials for base courses and to their construction. The materials should be dense and uniformly compacted so no differential settlement occurs in adjacent areas. For continuous stability, all base courses should meet the requirements listed below.

Gradation requirements.

- Gradation of particle size must, whenever feasible, be within specified limits as determined by mechanical analysis. However, in construction in forward areas it may not be practicable to hold to close gradation requirements.

- For deliberate construction base course material should contain no more than 15 percent passing a No. 200 sieve.

Plasticity requirements.

- Material passing the No. 40 sieve which acts as a binder in a basecourse material must have desirable properties. No material which has a liquid limit greater than 25 or a plasticity index greater than 5 should be used for a base course in deliberate construction.

Compaction and strength requirements.

- Thickness of layers in constructing base courses must be within the limits which will insure proper compaction. Thickness of layers depends upon type of material, equipment used, and method of construction used.
- All base courses must be compacted. Compaction should meet the requirements given in Figure 4.
- The CBR of the finished base course must conform to that used in the design, and the total compacted thickness must equal that obtained from the design curves, as previously discussed. Table 4 lists nine types of materials and/or processes that may be used as base courses for roads and airfields. A design CBR is given for each type.

BASE-COURSE MATERIALS

Natural materials. A wide variety of gravels, sands, gravelly and sandy soils, and other natural materials such as limerock, coral, shells, and some caliches can be used alone or blended to provide satisfactory base courses. In some instances, natural materials will require crushing or removal of the oversize fraction to maintain gradation limits. Other natural materials may be controlled by mixing crushed and pit-run materials to form a satisfactory base-course material.

Gravel and sand. Many natural deposits of sandy and gravelly materials make satisfactory base materials. Gravel deposits vary widely in the relative proportions of coarse and fine material and in the character of the rock frag-

TABLE 4. ASSIGNED CBR RATINGS FOR BASE COURSE MATERIALS

No.	Type	Design CBR
1	Graded crushed aggregate	100
2	Water-bound	100
3	Dry-bound macadam	100
4	Bituminous base course, central plant hot mix	100
5	Limerock	80
6	Bituminous macadam	80
*7	Stabilized aggregate	80
8	Soil cement	80
9	Sand shell or shell	80

*It is recommended that stabilized aggregate base course material not be used for tire pressures in excess of 100 psi.

ments. Satisfactory base materials often can be produced by blending materials from two or more deposits. Uncrushed, clean washed gravel is not satisfactory for a base course, because the fine material which acts as the binder and fills the void between coarser aggregate has been washed away. A base course made from sandy and gravelly material that meets the requirements given in base course requirement has a high bearing value and can be used to support heavy loads.

Sand-clay. Sand and clay in a natural mixture may be found in alluvial deposits varying in thickness from 1 to 20 feet. Often there are great variations in the proportions of sand and clay from top to bottom of a pit. Deposits of partially disintegrated rock consisting of fragments of rock, clay, and mica flakes should not be confused with sand-clay soil. Mistaking such material for sand-clay is often a cause of base-course failure because of reduced stability due to the mica content. With proper proportioning and construction methods, satisfactory results can be obtained with sand-clay. It is excellent in stage construction where a higher type of surface is to be added later.

Stabilized soil mixtures. The stabilization of soils by various methods is discussed in detail in EN 5453 and TM 5-530. All principal types of stabilized soils mixtures can be used as base courses beneath bituminous wearing surfaces.

Processed materials. Processed materials are prepared by crushing and screening rock, gravel, or slag. A properly graded crushed-rock base produced from sound, durable rock particles makes the highest quality of any base material. Crushed rock may be produced from almost any type of rock that is hard enough to require drilling, blasting, and crushing. Existing quarries, ledge rock, cobbles and gravel, talus deposits, coarse mine tailings, and similar hard, durable, rock fragments are the usual sources of proc-

essed materials. Do not use materials which slake on exposure to air or water, nor use processed materials if materials such as gravel or sand-clay are available, except when studies show that the use of processed materials will save time and effort or when they are made necessary by project requirements. Bases made from processed materials can be divided into three general types: stabilized, coarse graded, and macadam.

Stabilized base material. A stabilized type base course is one in which all the material ranging from coarse to fine is intimately mixed either before or as the material is laid into place. If practicable, materials for this type of base should meet the requirements given in Table 5. Because the aggregates produced in crushing operations or obtained from deposits are often deficient fines, it may be necessary to blend in selected fines to obtain a suitable gradation. Screenings, crusher-run fines, or natural soil containing no clay may be added and mixed either in the processing plant or during the placing operation.

TABLE 5. DESIRABLE GRADATION FOR CRUSHED ROCK, GRAVEL, OR SLAG, AND UNCRUSHED SAND AND GRAVEL AGGREGATES FOR BASE COURSES

Sieve Designation	Percent passing each sieve (square openings) by weight				
	Maximum aggregate size				
	3-inch	2-inch	1½-inch	1-inch	1-inch sand-clay
3-inch	100				
2-inch	65-100	100			
1½-inch	--	70-100	100		
1-inch	45-75	55-85	75-100	100	100
3/4-inch	--	50-80	60-90	70-100	
3/8-inch	30-60	30-60	45-75	50-80	
No. 4	25-50	20-50	30-60	35-65	
No. 10	20-40	15-40	20-50	20-50	65-90
No. 40	10-25	5-25	10-30	15-30	33-70
No. 200	3-10	0-10	5-15	5-15	8-25

Coarse-graded type base material. A coarse-graded type base course is composed of crushed rock, gravel, or slag. If practicable, material for this type of base should meet the gradation requirements given in Table 5. This base may be used to advantage when it is necessary to produce crushed rock, gravel, or slag on site or when commercial aggregates are available. When gravel is used, it is desirable that 90 percent of the material by weight have two or more freshly fractured faces, with the area of each face being equal to at least 75 percent of the smallest midsectional area of the piece.

Macadam type base material. The term macadam is usually applied to construction where a coarse, crushed aggregate is placed in a relatively thin layer and rolled into place; then fine aggregate or screenings are placed on the surface of the coarse aggregate layer and rolled and broomed into the coarse rock until it is thoroughly keyed in place. Water may be used in the compacting and keying process. When water is used, the base is termed a waterbound macadam. The crushed rock used for macadam base courses should consist of clean, angular, durable particles free of clay, organic matter, and other objectionable material or coating. Because of the method of construction, it is necessary to maintain the coarse and fine aggregates separately. Aggregates for macadam type construction should meet the gradation requirements given in Table 5. Any hard, durable crushed aggregate can be used, provided the coarse aggregate is primarily one size and the fine aggregate will key into the coarse aggregate.

Other materials. In many areas in a theater of operations, deposits of natural sand and gravel and sources of crushed rock are not available. This has led to the development of base courses from materials that normally would not be considered. These include caliche, limerock, shells, cinders, coral, iron ore, rubble, and other select materials. Some of these are primarily soft rock, and crush or degrade under construction traffic to produce composite base materials similar to those previously described. Others develop a cementing action which results in a satisfactory base. These materials cannot be judged on the basis of the gradation limits used for other materials, but must be judged on the basis of service behavior. Strength tests on laboratory samples are not satisfactory because the method of preparing a sample seldom duplicates the material in place. The plasticity index is a reasonably good criterion, and as a general rule, a low plasticity index is a necessity. Observation of the performance of these types of base materials in existing roads and pavements is the most reliable clue as to whether or not they will be satisfactory.

Coral. Coral is commonly found in the Pacific and Caribbean areas. Since uncompacted coral has a high capillarity, uncompacted and poorly drained coral often results in an excessive moisture content and loss of stability. The bonding properties of coral, which are its greatest asset as a construction material, vary with the amount of volcanic impurities, the proportion of fine and coarse material, age, length of exposure to the elements, climate, traffic, sprinkling; and method of compaction. Proper moisture control, drainage, and compaction are essential to obtain satisfactory results. Variations over 1 percent from OMC should be avoided. Sprinkling with sea water or sodium chloride in solution has a beneficial effect on bonding when rollers are used. However, because of the possible corrosive effects on aircraft engines, sprinkling with sea water on airfields should be undertaken only with specific approval of higher authority.

TABLE 6. DESIRABLE GRADATIONS OF AGGREGATE FOR DRYBOUND AND WATERBOUND MACADAM BASE COURSES

DRYBOUND

Sieve designations	Percentage by weight passing each square-mesh sieve						
	Coarse aggregate gradation				Choker aggregate gradation		Screenings
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
3-inch	100	100					
2½-inch	90–100	90–100	100				
2-inch	35–70		90–100	100			
1½-inch	0–15	25–60	35–70	90–100			
1-inch			0–15	20–55			
¾-inch	0–5	0–10		0–15	100		
½-inch		0–5	0–5		90–100		
⅜-inch				0–5		100	100
No. 4						85–100	85–100
No. 100					10–30	10–30	5–25

WATERBOUND

Sieve designations	Percentage by weight passing each square-mesh sieve				
	Coarse aggregate gradation			Screening gradation	
	No. 1	No. 2	No. 3	No. 4	No. 5
3-inch	100	100			
2½-inch	90–100	90–100	100		
2-inch	35–70		90–100		
1½-inch	0–15	25–60	35–70		
1-inch			0–15		
¾-inch	0–5	0–10		100	
½-inch		0–5	0–5	90–100	
⅜-inch					100
No. 4					85–100
No. 100				10–30	10–30

Caliche. One of the fairly common characteristics of many caliches which make them valuable for base courses is their quality of recementation upon being saturated by water, subjected to compaction, and given a setting period. This is especially applicable to caliches which are cemented with lime, iron oxide, or salt. Caliche is variable, however, in content (limestone, silt, and clay) and in the degree of cementation; therefore, it is important that caliche of good uniform quality be obtained from deposits and that it be compacted at optimum moisture. After caliches have been slaked for 72 hours the liquid limit of the -40 fraction should not exceed 35, and the plasticity index should not exceed 10. For base course material, caliches should be crushed to meet the following gradations:

	Percent
Passing 2-inch square mesh..............	100
Passing No. 40 sieve.........................	15-35
Passing No. 200 sieve.......................	0-20

Where the construction is to be made on surface deposits, undesirable material is removed by stripping operations.

Tuff. Tuff and other cementaceous materials of volcanic origin may be used for base courses. Tuff bases are constructed the same as other base courses except that after the tuff is dumped and spread, the oversize pieces are broken and the base compacted with sheepsfoot rollers. The surface is then graded, and final compaction and finishing are done.

Rubble. In many cases it may be advantageous to use the debris or rubble of destroyed buildings in constructing base courses, but care must be exercised to see that jagged pieces of metal and similar objects are removed. Before removing any rubble, check for mines or boobytraps.

Bituminous base. Bituminous mixtures frequently are used as base courses beneath high type bituminous pavements, particularly for rear area type airfields which carry heavy traffic. Such base courses may be used to advantage when aggregates locally available are relatively soft and otherwise of relatively poor quality, when mixing plant and bituminous materials are readily available, and when a relatively thick structure is required for the traffic. In general, a bituminous base course may be considered equal on an inch-for-inch basis to other types of high-quality base courses. When a bituminous base course is used, it will be placed in lifts not exceeding 3½ inches in thickness. If a bituminous base is used, you may omit the binder course and lay the surface course directly on the base course.

Selection of Type of Base Course

Selection of the type of base construction depends principally upon materials available at the particular site, but equipment available and prevailing weather conditions during construction also are important factors. A complete investigation should be made to determine the location and characteristics of all natural materials suitable for base-course construction. Construction of untreated base courses with natural materials is affected less by adverse weather than other types and requires less technical control. Untreated bases are relatively easy and fast to build and are recommended in preference to bituminous or cement-stabilized types, except where suitable materials for such construction are more readily available. If they are not locally available, the transportation of bituminous material or cement for base stabilization is a major supply problem in forward areas.

Learning Event 3
DESIGN THEATER OF OPERATIONS ROADS

Introduction

The areas in the Theater of Operations needing paved roads to support the operational requirements can be broken down into four general categories:

- division support areas
- corps support areas
- Army areas
- CommZ – communication zone.

In each case, the acceptable and more accurate design method consists of estimating the number of operations each type of vehicle is expected to use on the proposed road during its design life. In this Learning Event, you will learn how to determine the traffic composition and convert it to equivalent 18,000 pound operations.

Design Method

The design of a flexible pavement to be used as a military road in a Theater of Operations consists of:

- Estimating the number of operations for each type of vehicle that is expected to use the proposed road during its design life. This may be based on knowledge of traffic using similar use roads or on anticipated traffic. It must be borne in mind that the greatest influence on thickness design is the type and number of operations of very heavy vehicles. This will be made clear later in an example.

- Estimating how long a period of time the proposed road will be needed. This is called the "design life."

- Converting the operations of each type of vehicle into equivalent 18,000 pound, single-axle, dual-wheel load operations through the use of equivalent operations factors shown in Figures 6 and 7.

- Computing cover requirement from the equivalent operations in the design life from Figure 8.

Statement of Requirement. A main supply route is to be designed for a 2-year design life on a subgrade with a CBR value of 10. The road is to be an all weather road and materials and equipment are available to construct an asphalt concrete surface. Ample quantity of base course material with a CBR of 50 is available. In addition, a pit has been located adjacent to the road site that will furnish material for subbase with a CBR value of 40.

Anticipated Traffic. From a study of previous main supply routes in the same general area, the following estimation of anticipated traffic is made:

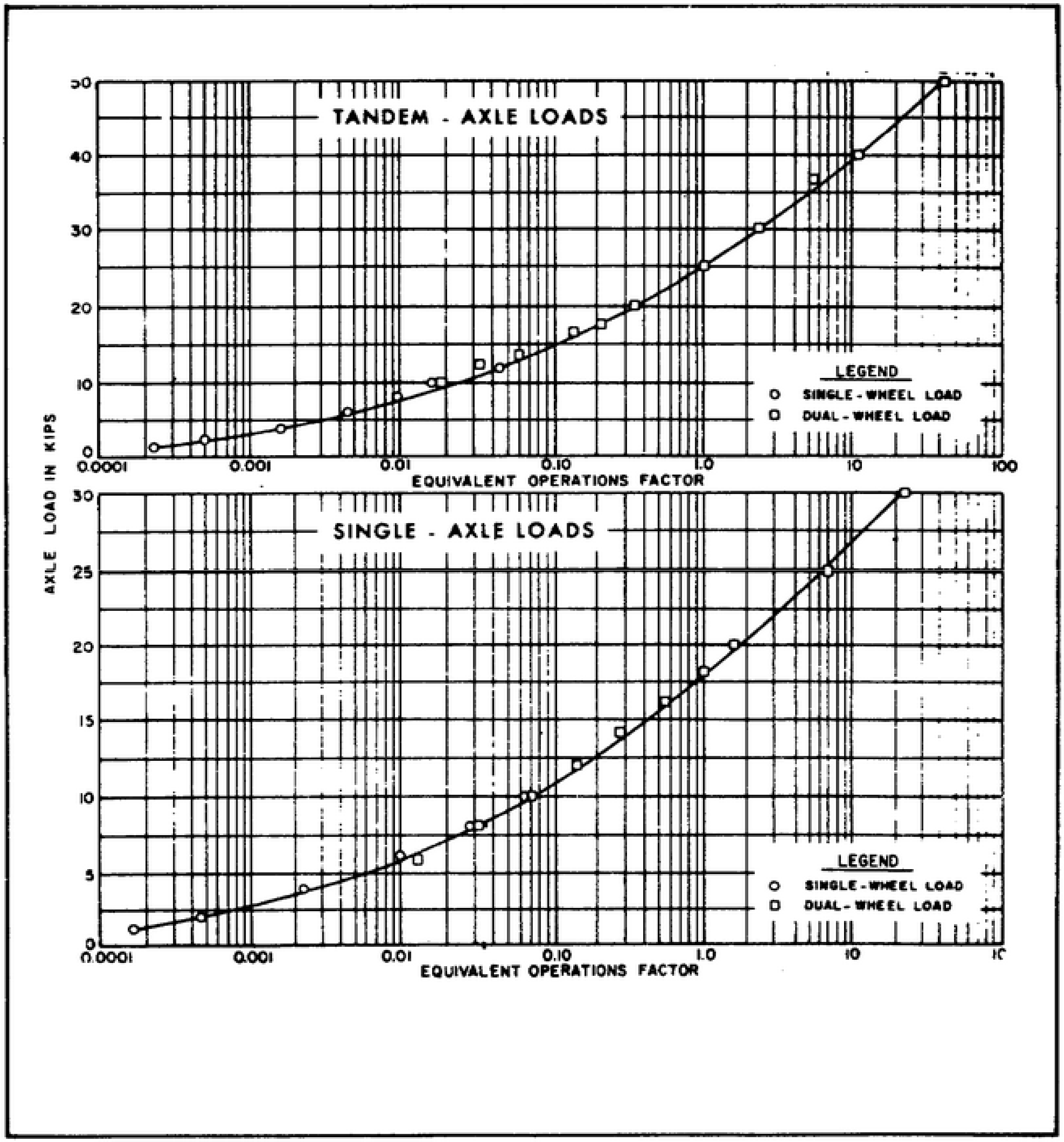

FIGURE 6. FLEXIBLE PAVEMENT EQUIVALENT FACTORS

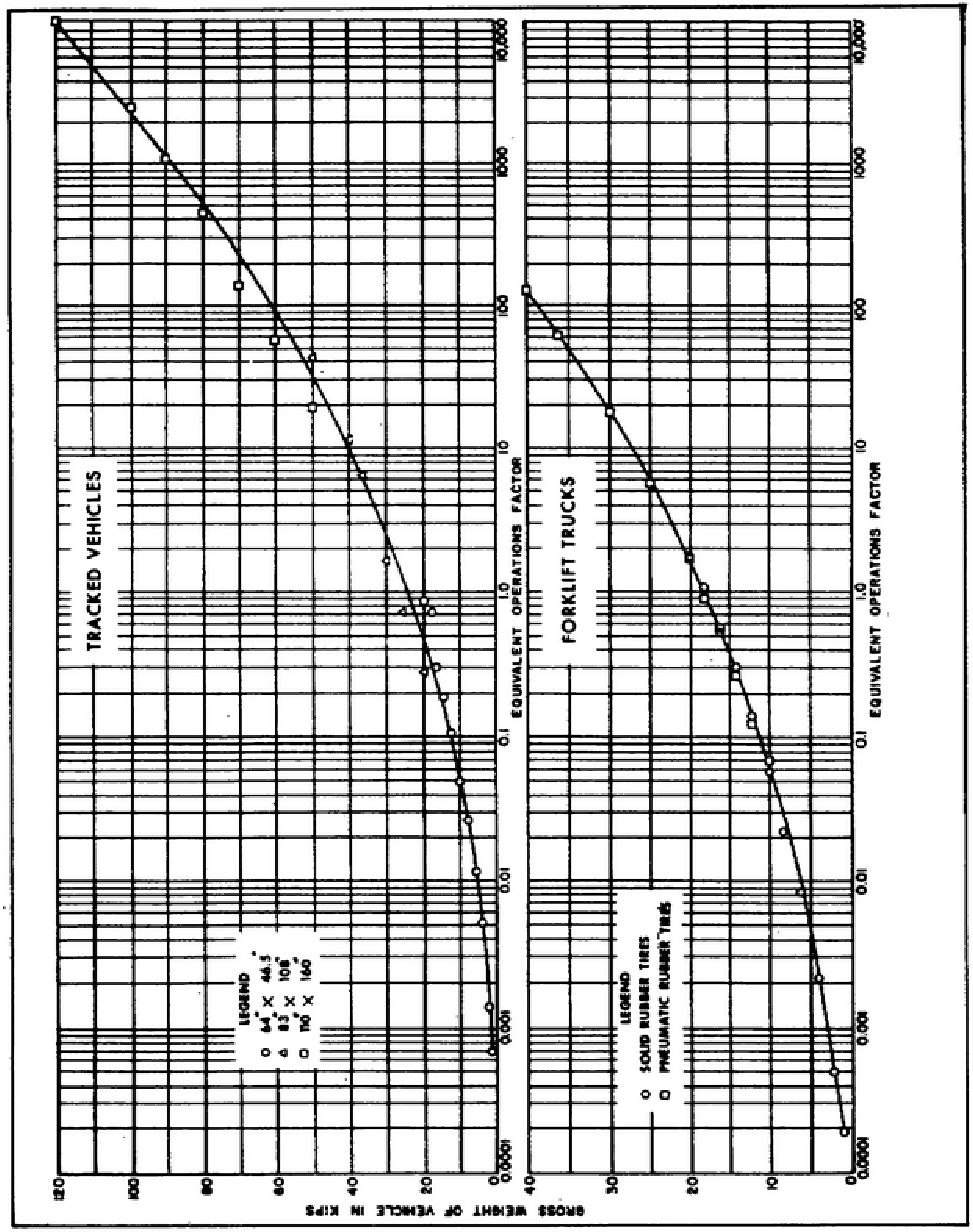

FIGURE 7. FLEXIBLE PAVEMENT EQUIVALENT FACTORS

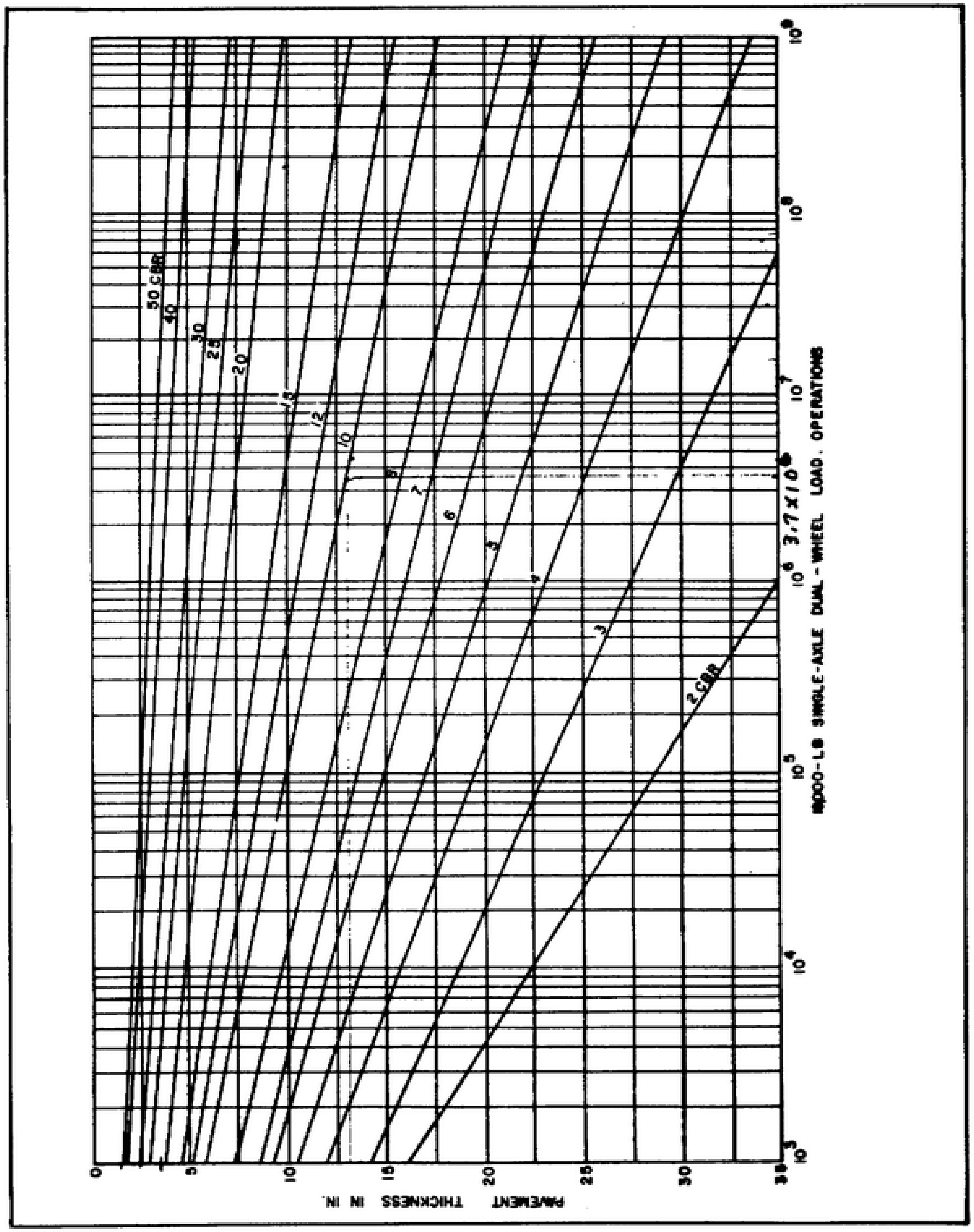

FIGURE 8. FLEXIBLE PAVEMENT DESIGN CURVES FOR ROADS

TABLE 7. VEHICLE OPERATIONS PER DAY

Axle or Gross Loads lb	Single Axle Operations per day	Tandem Axle Operations per day	Tracked Vehicle Operations per day
1,000	500	....	....
1,500	400	....	....
3,000	300	....	....
4,000	100	....	....
5,000	....	20	....
10.000	50	100	25
20,000	20	200	....
30,000	....	50	....
32,000	....	....	15
80,000	....	....	10

Equivalent 18,000 Pound Load Operation.

- Convert operations per day of these axle and gross loads into equivalent 18,000 single-axle, dual-wheel load operations through use of the equivalent operations factor curves in Figures 6 and 7.

TABLE 8. EXAMPLES OF CALCULATING EQUIVALENT OPERATIONS

		Single-Axle			
1,000	0.00016	x	500	=	0.08
1,500	0.0003	x	400	=	0.12
3,000	0.0012	x	300	=	0.36
4,000	0.0028	x	100	=	0.28
10,000	0.07	x	50	=	3.50
20,000	1.8	x	20	=	36.00
					40.34
		Tandem-Axle			
5,000	0.0031	x	20	=	0.062
10,000	0.024	x	100	=	2.4
20,000	0.360	x	200	=	72.0
30,000	2.30	x	50	=	115.0
					189.462
		Tracked Vehicles			
10,000	0.050	x	25	=	1.25
32,000	2.70	x	15	=	40.50
80,000	480.0	x	10	=	4800.00
					4841.75
TOTAL EQUIVALENT OPERATIONS PER DAY =					5071.55

- Equivalent operations for a 2-year period: 365 days x 2 years x 5072 equivalent operations per day = 3,702,560 or 3.7 x 10^6.

- It can be seen that although the actual number of tracked vehicle operations is small, the number of equivalent operations of tracked vehicles is very large and has the greatest influence on the thickness requirements of all three vehicle categories.

Thickness Requirements.

- The thickness requirements are found by using Figure 8.

- Enter Figure 8 at 3.7 x 10^6 equivalent operations and proceed vertically to the CBR 10 line, then horizontally to the left to the cover required. It is found that the CBR 10 material must have a cover of 13 inches.

- Table 8 indicates that the minimum thickness of pavement and base course for CBR 50 material with an anticipated traffic of 3.7 x 10^6 equivalent operations is 3 1/2 inches of pavement and 4 inches of base course. This is in excess of the cover requirement of 4 inches over the CBR 40 material.

- Figure 9, #1, illustrates the proposed design for the flexible pavement structure.

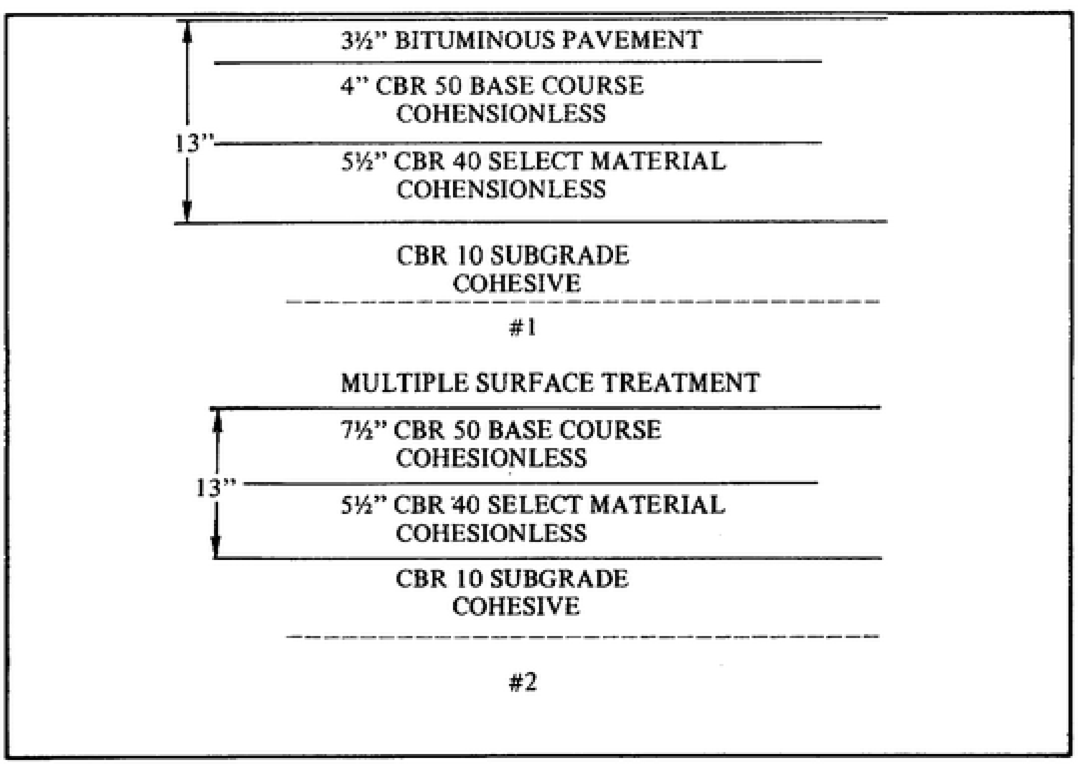

FIGURE 9. ROAD DESIGN

- The most common type of bituminous wearing surface that can be expected to be constructed in the theater of operations is the surface treatment. Experience from the use of surface treatments over base courses with CBR less than 80 has shown that constant maintenance is necessary.

- Assume in the above example that the pavement could not be placed due to lack of materials and equipment and surfacing would be limited to a multiple surface treatment. The construction in this example problem is limited to the use of materials-of CBR 40 subbase and CBR 50 base course. When Figure 6 was used in the above example, it was found that a minimum of 3/2 inches of pavement was required over the CBR 50 material. Since neither the pavement material nor material higher than CBR 50 is available, it is necessary to use the CBR 50 material to meet the cover requirements. Heavy maintenance will be required, however.

- Figure 9, #2 illustrates the design for the multiple surface treatment.

Determine Cover Requirements for Subbase and Base

The method you use to determine the cover requirements for subbase and select material is the same method you used to determine the total structure thickness in Learning Event 5. Enter the horizontal scale at the proper EODL, proceed upward until it intersects the correct CBR curve line, then left to determine the correct cover requirements in inches. For example, using Figure 8, an EODL is 3.7×10^6 and the subbase CBR is 40. You will find that the cover requirement is 4 inches.

Use the same method to determine the cover requirement for the base as for the subbase and the total structure thickness. (Refer to Table 8.)

For example, using Figure 8, an EODL is 3.7×10^6 and the base CBR is 50. You will find that the cover requirement is 3.5 inches. Table 9 shows the recommended minimum thickness of pavements and base courses for roads.

TABLE 9. RECOMMENDED MINIMUM THICKNESS OF PAVEMENT AND BASE COURSE FOR ROADS

Equivalent 18,000 lb single-axle wheel load operations	100 CBR Base Pavement (in)	100 CBR Base Base (in)	100 CBR Base Total (in)	80 CBR Base Pavement (in)	80 CBR Base Base (in)	80 CBR Base Total (in)	50 CBR Base Pavement (in)	50 CBR Base Base (in)	50 CBR Base Total (in)
3×10^2 or less	ST[a]	4	4½	MST[b]	4	5	1½	4	5½
3×10^2 - 1.5×10^4	ST	4	4½	MST	4	5	2	4	6
1.5×10^4 - 7×10^4	MST	4	5	1½	4	5½	2½	4	6½
7×10^4 - 10×10^5	MST	4	5	1½	4	5½	3	4	7
7×10^5 - 7×10^6	1½	4	5½	2	4	6	3½	4	7½
7×10^6 - 7×10^7	1½	4	5½	2½	4	6½	4	4	8
7×10^7 - 7×10^8	2	4	6	3½	4	7½	4½	4	8½
7×10^8 - 2×10^9	3	4	7	3½	4	7½	5	4	9

a – Single bituminous surface treatment.
b – Multiple bituminous surface treatment.

Expedient Flexible Pavement Design for Road

As a starting basis for the expedient flexible pavement road design, the following equivalent loadings (Table 7), in terms of 18,000 lb single-axle dualwheel loads per day per Division, number of Divisions supported, and design life are suggested. In this tabulation the most critical Division load was selected for the Division Support Area, whereas in the other areas the Division loads were adjusted to more closely reflect the tactical needs. In each case, it is strongly recommended that you select the appropriate equivalent Division operations per day for the area you are in and multiply it by the actual

TABLE 10. SUGGESTED STARTING BASIS FOR EXPEDIENT FLEXIBLE PAVEMENT ROAD DESIGN

Area	Equivalent Operations/ Day	Minimum Design Life Conventional	Minimum Design Life Unconventional	*Total Equivalent Loadings Conventional	*Total Equivalent Loadings Unconventional
Division Support					
1 Division	5,000	45 days	8 months	2.5×10^5	1.0×10^6
Corps Support					
1 Division	3,500				
3 Divisions	10,500	5 months	8 months	1.5×10^6	2.5×10^6
4 Divisions	14,000	5 months	8 months	2.0×10^6	3.5×10^6
Army Area					
1 Division	3,000				
6 Divisions	20,000	9 months	9 months+	5.0×10^6	5.0×10^6+
12 Divisions	40,000	9 months	9 months+	1.0×10^7	1.0×10^7+
COMMZ					
1 Division	3,500				
6 Divisions	20,000	15 months	15 months+	9.0×10^6	9.0×10^6+
12 Divisions	40,000	15 months	15 months+	2.0×10^7	2.0×10^7+

*(Figures rounded off to 2 significant figures)

number of Divisions using the road and days of design life rather than accepting the values presented above. Only use the total equivalent loadings presented in Table 10 as a last resort for computing the needed cover requirements.

Learning Event 4.
COMPACTION REQUIREMENT AND FINAL DESIGN PROFILE

Introduction

Compaction requirements must be specified for each layer of the flexible pavement. CBR values for the various materials are based upon proper compaction. Additionally, proper compaction will reduce the amount of settling, which will help maintain a relatively smooth, well-drained surface free of potholes and bird baths.

Enter Compaction Requirements

Once the compaction requirements for each of the courses (materials) have been determined, they must be entered on the final design profile. The method used to enter the compaction requirements is shown in Figure 10.

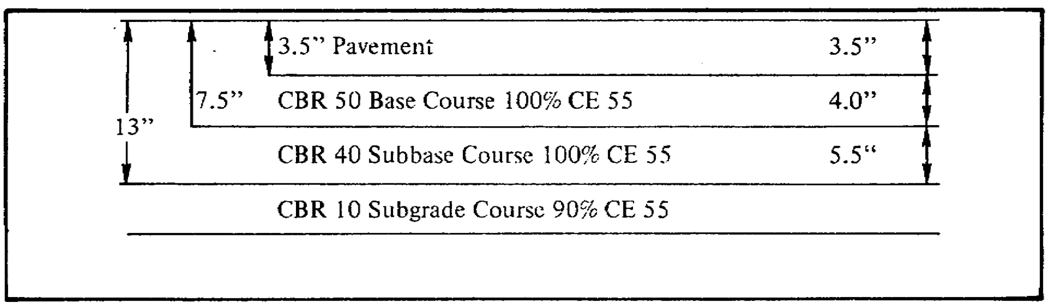

FIGURE 10. FINAL DESIGN PROFILE

Design of Pavement Courses. A bituminous pavement may be of one or more courses depending on the economic use of materials, stage construction factors, and job conditions. The pavement should consist of a surface course and a binder course (and leveling course when needed) of sufficient thickness to prevent displacement of the base course due to shear deformation, to provide long life, to be resistant to the effect of wear and traffic abrasion, and to minimize differential settlements. The recommended minimum thicknesses of pavements are shown in Table 9. It is recommended that all road pavements thicker than 2.5 inches be laid in two or more courses as shown in Figure 11.

Pavement	Binder Course	Surface Course
1.5 inches		1.5 inches
2 inches		2 inches
2.5 inches		2.5 inches
3 inches	1.5 inches	1.5 inches
3.5 inches	2 inches	1.5 inches
4 inches	2.5 inches	1.5 inches

FIGURE 11. RECOMMENDED MINIMUM THICKNESSES OF PAVEMENTS

Problem #1: T/O Road Design

Design a T/O Road with a design life of 2 years. It has the following anticipated daily traffic:

Axle or Gross Load (kips)	Single Axle Opns	Tandom Axle Opns
10	72	
12.5	70	
35.0		51

The following materials are available:

Surface	-	Asphalt Concrete Pavement, Surface Treatment
Base	-	Graded, Crushed Aggregate, Borrow Material, GP-GC
Subbase	-	CBR = 40, Max. size = 2", 57% passes through the #10 sieve, 12% passes through the #200 sieve, LL = 8, PI = 4
Select	-	None
Subgrade	-	ML-CL, PI = 15, CBR = 10

Solution:

Step 1 Check Materials

(1) The base material has a CBR of 100. (Table 3)
(2) The borrow material meets the criteria for CBR 40. (Table 12)

Step 2 Determine EODL (Figure 6)

	Weight	Ops Factor	Ops/Day	Equip Ops/day
Single	10	0.07	72	5.04
Single	12.5	0.20	70	14
Tanden	35	5	51	255
				274.04

$$\text{EDOL} = 2 \text{ yrs } \frac{(365 \text{ days})}{\text{yr}} \frac{(274.04 \text{ ops})}{\text{day}} = 200{,}049.2 = 2.00\text{x}10^5 \text{ ops}$$

Step 3 - Determine Cover Requirements (Figure 8)

Material	Cover Required
10	11"
40	3"

<u>Step 4</u> - Determine Surface and Base Thickness (Table 9)

For 100 CBR Base, Pavement = Multiple Surface Treatment (1')
Base = 4" (minimum)

<u>Step 5</u> - Determine Thickness Design

Surface	1" MST	3" Min	
Base	4" CBR 100		
Subbase	6" CBR 40 (11" - 4" - 1" = 6")		11" Min
Subgrade	CBR 10		

<u>Step 6</u> - Add Compaction, Draw Final Design Profile

1" MST	
4" CBR 100	100% CE55
6" CBR 100	100% CE55
CBR 10 SUBGRADE	90% CE55 (cohesive)

Practice Exercise for Lesson 1

PRACTICE EXERCISE FOR LESSON 1

Instructions

Check your understanding of Lesson 1 by completing the practice exercise. There is only one correct answer to each question. Try to answer all of the questions without referring to the lesson materials.

When you have completed all of the questions, turn the page and check your answers against the correct responses. Each correct response is referenced to specific portions of the lesson material so that you can review any questions you have missed or do not understand, before continuing to the next lesson.

Use Table 3, Page 16, for Question 1.

1. What are the requirements for the percentage of gradation passing the #10 sieve for a road with a design CBR of 40?

   a. 50 percent
   b. 80 percent
   c. 90 percent
   d. 100 percent

2. Which of the four layers in a flexible pavement are most affected by tire pressure variation?

   a. the surface course
   b. the base course
   c. the subbase course
   d. the subgrade

3. You have laboratory reports that show that select material has a plasticity index (PI) value of 7. What percent of compaction (Modified ASSHO, CE 55 Compactive effort) would you specify?

   a. 100 percent
   b. 95 percent
   c. 90 percent
   d. 85 percent

4. What is the compaction requirement for a base course?
   a. 85 percent
   b. 90 percent
   c. 95 percent
   d. 100 percent

Use Figure 6, page 24, for Question 5.

5. Determine the equivalent operations factor for a single axle load of 10,000 pounds.

   a. .07
   b. .10
   c. 1.5
   d. 2.0

6. What is the total minimum thickness of a 20 CBR subbase and an EODL of 7.3 x 10^6?

   a. 6 inches
   b. 7 inches
   c. 8 inches
   d. 9 inches

7. What is the cover required over a CBR 15 subgrade with a EODL of 2.9 x 10^8?

   a. 12.5 inches
   b. 15 inches
   c. 15.5 inches
   d. 17.5 inches

8. Using the equivalent operation per day 3782 and a design life of 3 years, determine the design life equivalent operation (EODL).

   a. 2,563,574
   b. 4,141,290
   c. 4,730,524
   d. 7,320,128

PRACTICE EXERCISE ANSWERS

Lesson 1	Learning Event
1. b	1
2. a	1
3. c	2
4. d	2
5. a	3
6. c	3
7. a	3
8. b	3

Lesson 2

DESIGN AN AIRFIELD FLEXIBLE PAVEMENT

TASK: Design flexible pavement for airfields and heliports.

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by responding correctly to 75% of the examination questions.

CREDIT HOURS: 4

REFERENCES

Learning Event 1
OPERATIONAL CATEGORIES

Introduction

An airfield is composed of many elements. Runways, taxiways, aprons, and hardstands, normally consist of a pavement placed on a stabilized or compacted subgrade. Shoulders and clear zones are normally composed of compacted in-place materials. Approach zones and lateral safety zone require only clearing above the prescribed glide angle and safety angle. The acceptable design method consists of determining the type of aircraft to use the airfield, the type of operational category, traffic areas involved, and the design gear loads of the aircraft. In this learning event you will learn how to determine the type of airfield required.

Determine the Design Aircraft; Determine Operational Category; and Determine Traffic Area

Determine the Design Aircraft

The Theater of Operations design system allows for the design of a flexible pavement for each aircraft in the Air Force and Army inventories. However, doctrine stipulates that flexible pavements will normally be constructed for the following airfield types, all of which are located in the COMMZ (Communication Zone).

Type Airfield	DESIGN AIRCRAFT (based on critical load)
Rear Area, Heavy Lift	C-141
Rear Area, Tactical	C-4C
Rear Area, Army	OV-1

See Table 12-3 for characteristics of aircraft.

Determine Operational Category

Each type of airfield shown above is subdivided into the following operational categories according to the construction effort, anticipated design life, and estimated maintenance requirements (Table 11).

TABLE 11. RELATIONSHIP BETWEEN TRAFFIC AND PAVEMENT DESIGN THICKNESS

Classification by construction type	Max No. coverages	Approx No. of cycles	Anticipated pavement life	Pavement thickness	Maintenance
Emergency	40	100-500 cargo 800 fighter	2 wks	60% full operational	Heavy and continuous
Minimum operational	200	500-1,800 cargo 4,000 fighter	6 mo	80% full operational	Daily
Full operational	1,000	2,500-12,000 cargo; 20,000 fighter	2 yr	Full operational	Weekly

Determine Traffic Areas

Theater of Operations airfield pavements can be grouped into two traffic areas, designated type B and type C, as defined below.

Type B

Type B traffic areas are those in which the traffic is more evenly distributed over the full width of the pavement but which receive the full design weight of the aircraft during traffic operations. These areas are:

1. End 1,000 feet of runways
2. Primary taxiways
3. All aprons, warm-up hardstands, and aircraft power-check pads.

Type C

Type C traffic areas are those in which the volume of traffic is low or the weight of the operating aircraft is less than the design weight. This area is the interior portion of runways between the 1,000 foot ends.

Figure 12 shows the traffic are of a typical Theater of Operations airfield. Additional information about traffic areas can be found in TM 5-330.

Selection of Design for Select Material and Subbases

The selection of materials is the same as in Lesson 1, Learning Event 2.

TABLE 12. RECOMMENDED MAXIMUM PERMISSIBLE VALUES OF GRADATION AND ATTERBERG LIMIT REQUIREMENTS IN SUBBASES AND SELECT MATERIALS FOR AIRFIELDS

Material	Maximum design CBR	Size, inches	Gradation requirements % passing No. 10	Gradation requirements % passing No. 200	Atterberg limits LL	Atterberg limits PI
Subbase	50	3	50	15	25	5
Subbase	40	3	80	15	25	5
Subbase	30	3	100	15	25	5
Select material .	Below 20	3	. . .	25	35	12

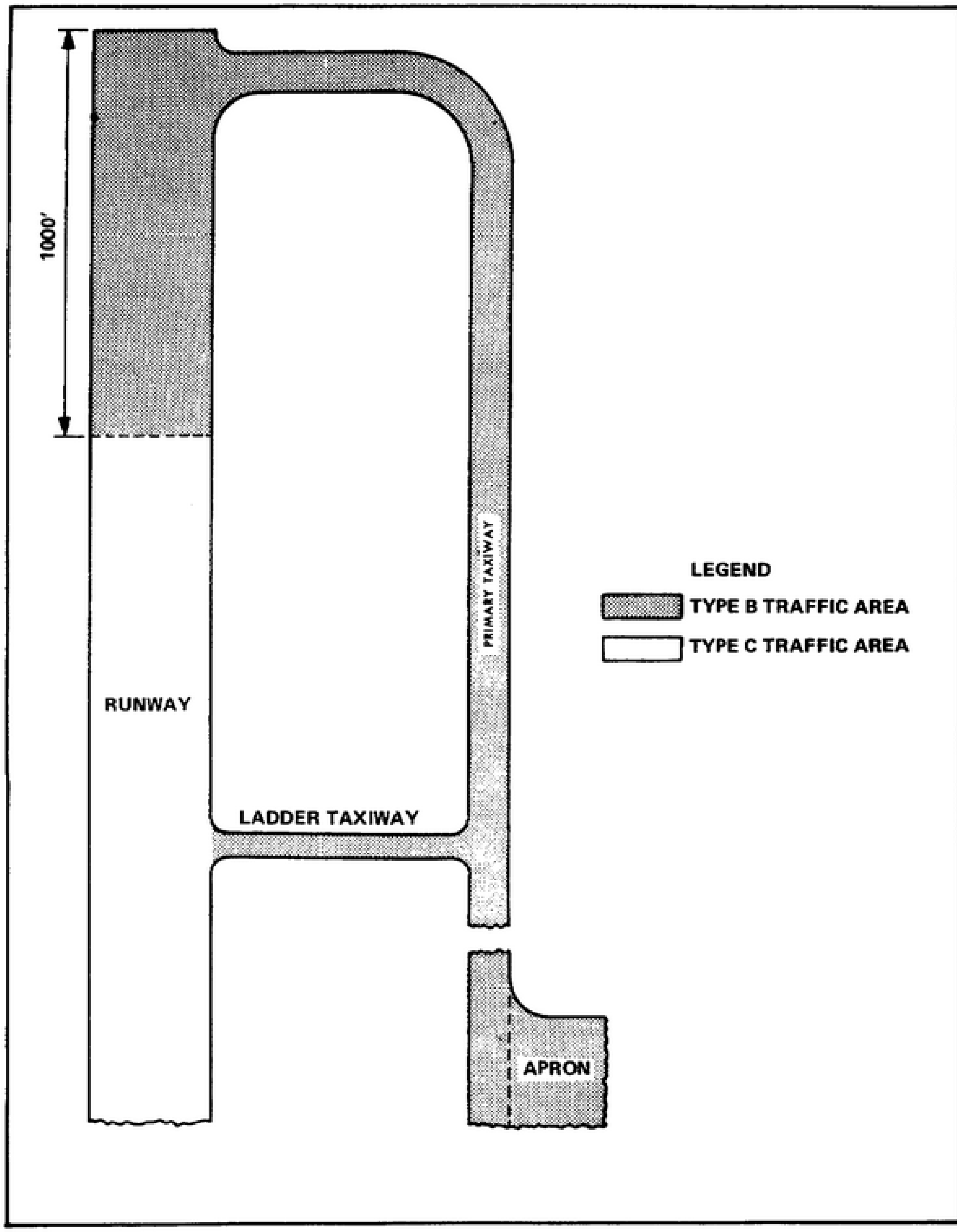

FIGURE 12. TRAFFIC AREAS

Learning Event 2
DESIGN CURVES AND LOAD

The design curves represent the recommended required thicknesses of stable material above the layer being considered. Each type of aircraft in the Air Force inventory has an assigned flexible pavement design and evaluation curve. These curves are shown in Figures D-25 through D-37, Appendix of this subcourse. To determine which design curve to use you must know the type of aircraft and the operational category of the airfield. For example, if you were constructing an emergency operational airfield for use by C-123B aircraft, you would select the design curve shown in Figure 13.

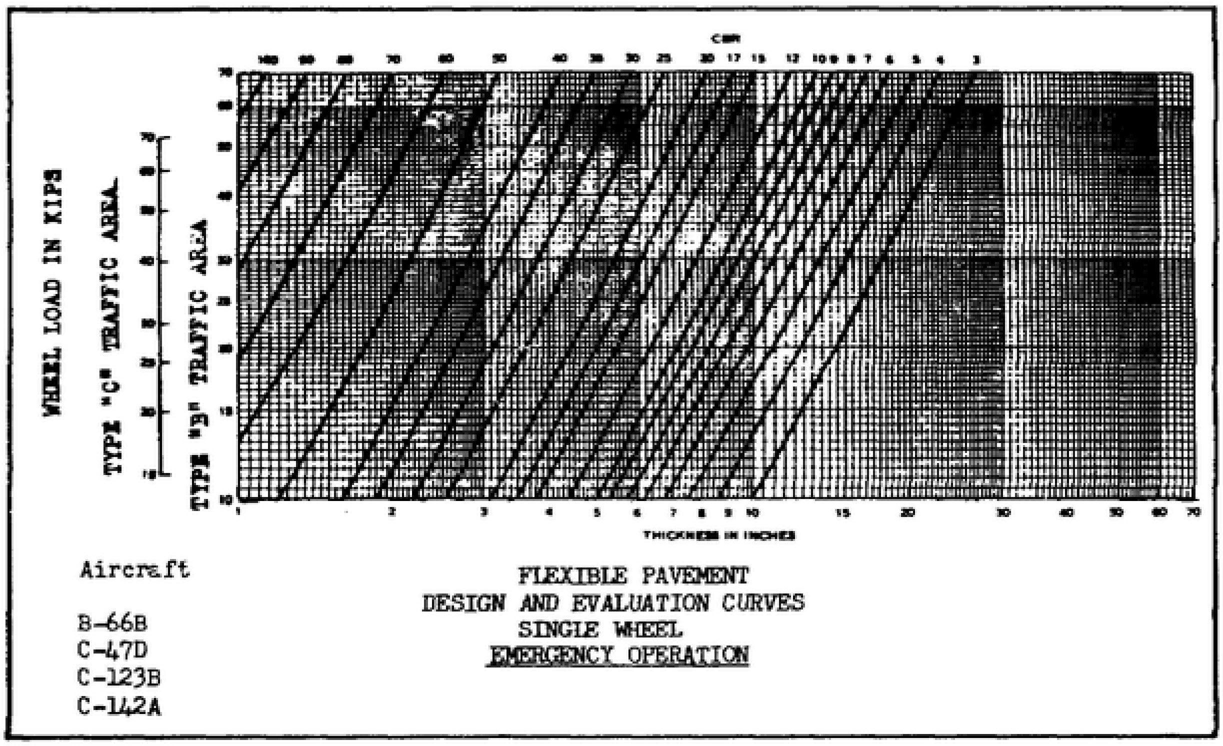

FIGURE 13

More information on selecting design curves can be found in TM 5-330.

Select Design Gear Loads in KIPS

A design gear load for each type of aircraft in the Air Force inventory has been established. These gear loads are shown in tips (1 kip = 1000 pounds). The established gear load for each type of aircraft is listed in Table 13-10 (located in the appendix). Using Table 13-10, select the correct gear load for a C-141A aircraft. You should find that the gear load is 149,500 pounds or 149.5 kips. Table 13-10 also shows the recommended minimum thickness of pavement and base course for a flexible pavement. For example, for an Air Force airfield, which is fully operational with a

CBR base of 80, and which is used by C-130E aircraft, the minimum pavement thickness is 3 inches. The minimum base thickness for an Air Force airfield is 6 inches. The minimum base thickness for an Army airfield is 4 inches.

Additional information about design gear loads can be found in TM 5-330.

Design Requirements

Flexible pavement designs must provide sufficient compaction of the subgrade and each pavement layer to prevent objectionable settlement under concentrated and repeated traffic. Compaction requirements are given in Lesson 1, Figure 4. Flexible pavement designs must also provide adequate thickness of quality pavement components above the subgrade to prevent detrimental subgrade deformation, excessive deflection of the pavement surface, and excessive tensile strain in the surface pavement material under traffic. In addition, the flexible pavement design must provide a stable, weather resistant, wear resistant, and non-skid surface.

Thickness Design

From the procedures included herein, the total thickness of the pavement, as well as the thicknesses of individual courses may be determined. These thicknesses, together with the minimum thicknesses for surface and base courses, provide the basis for pavement section design. See Table 13 for an outline of the flexible pavement thickness design procedure.

TABLE 13. CBR FLEXIBLE PAVEMENT DESIGN PROCEDURE

Item	Procedure
Total Thickness	1. Determine design CBR of subgrade. 2. Enter top of flexible pavement design curve (Figures 14 and 16) with design subgrade CBR and follow it downward to intersection with appropriate gross weight curve, then horizontally to appropriate aircraft passes curve then down to required total pavement thickness above subgrade.
Thickness of Surface and Base Course	3. Determine design CBR of subbase material. 4. Enter top of curve at design CBR of subbase, follow procedure in procedure 2 above to obtain required thickness of base and surface above subbase course. 5. Determine the required minimum thickness of base and surface from Tables 9 to 11. Increase combined thickness of base and surface to required minimum, if necessary.
Thickness of Subbase Course	6. Subtract thickness of surface and base from the total thickness to obtain the required thickness of subbase. 7. If less than six inches, consider increasing thickness of base course.
Subgrade Compaction	8. See Figure 4 for required compaction of subgrade.

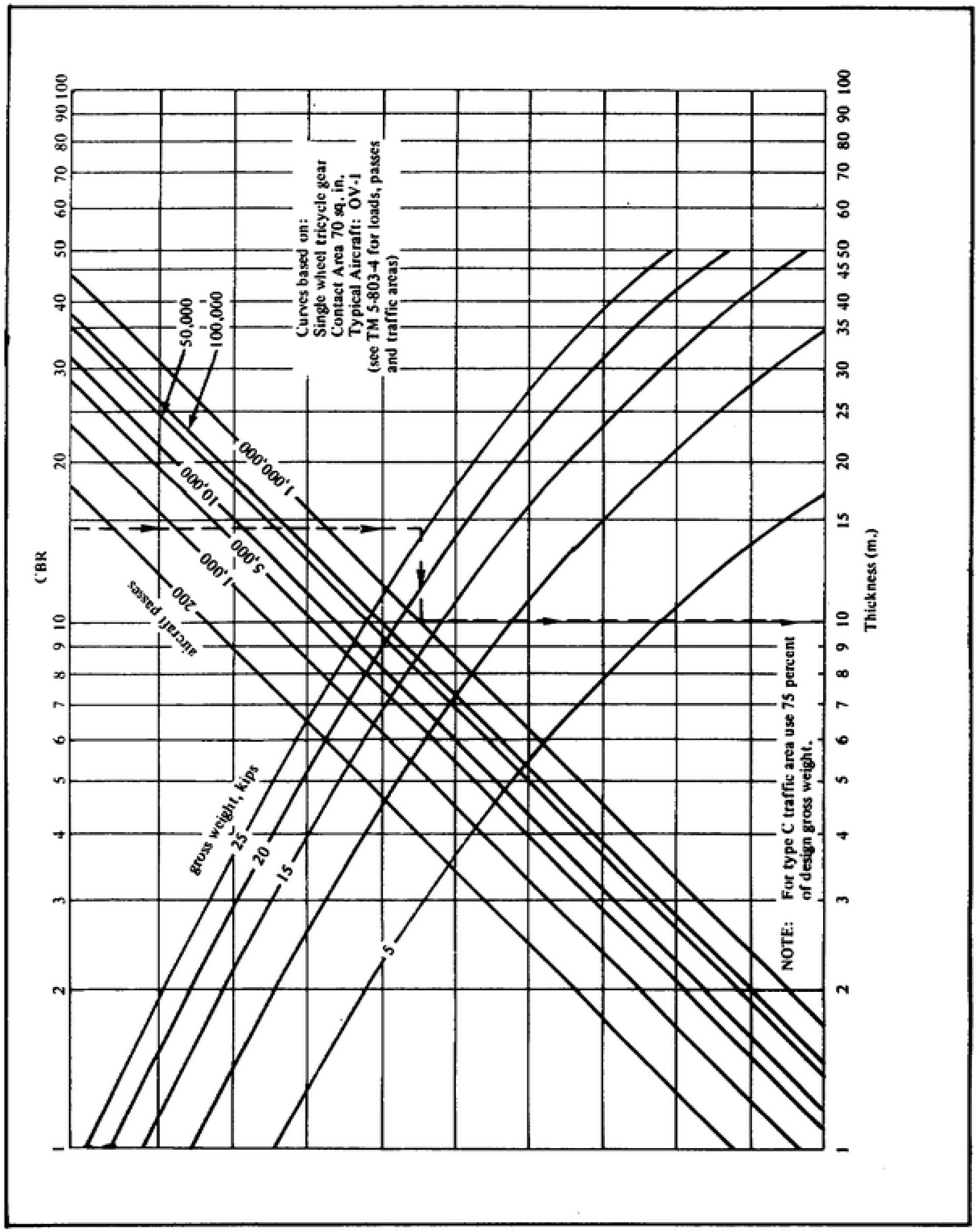

FIGURE 14. FLEXIBLE PAVEMENT DESIGN CURVES, ARMY CLASS I AIRFIELD, TYPES B AND C TRAFFIC AREAS

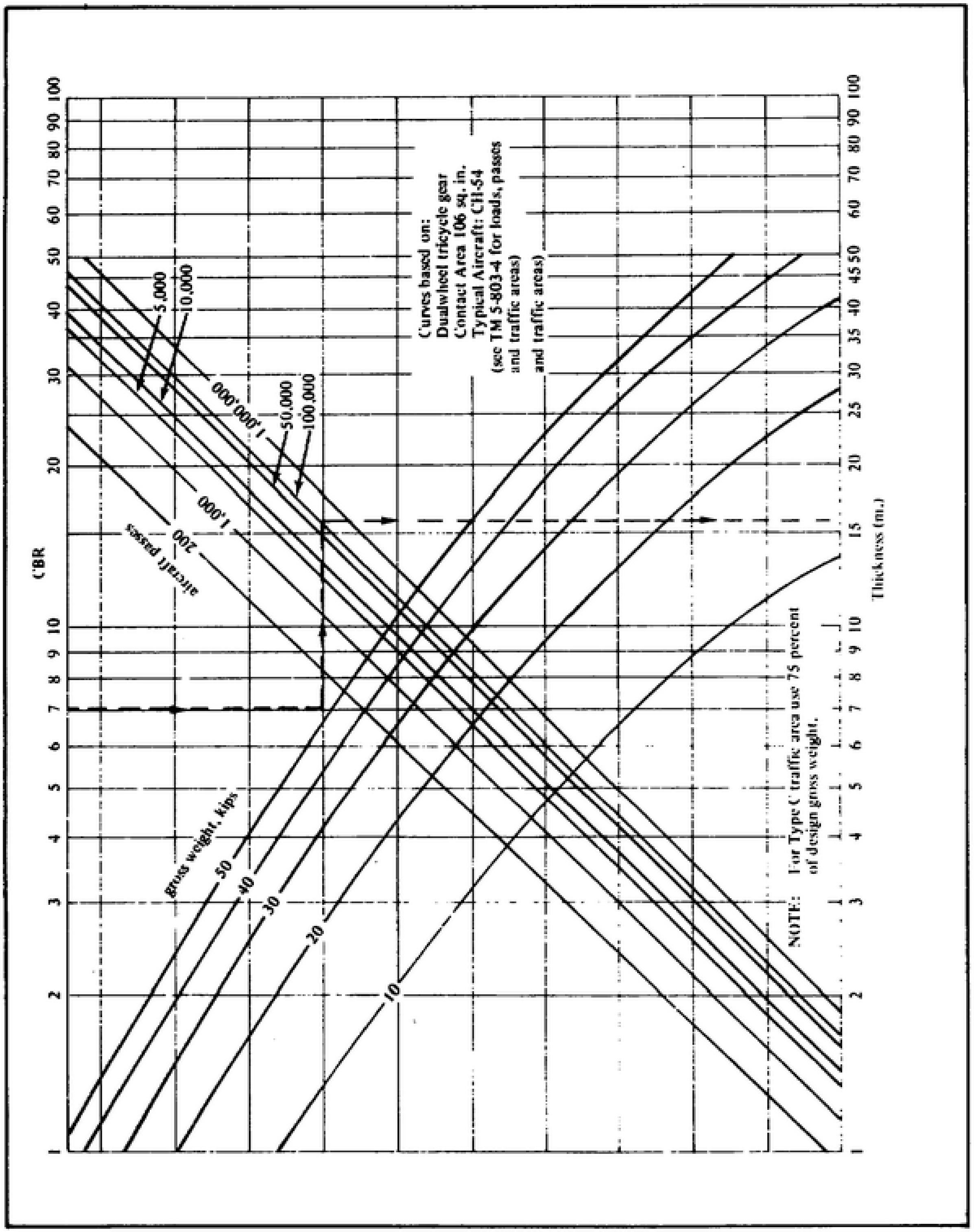

FIGURE 15. FLEXIBLE PAVEMENT DESIGN CURVES, ARMY CLASS II AIRFIELD, TYPES B AND C TRAFFIC AREAS

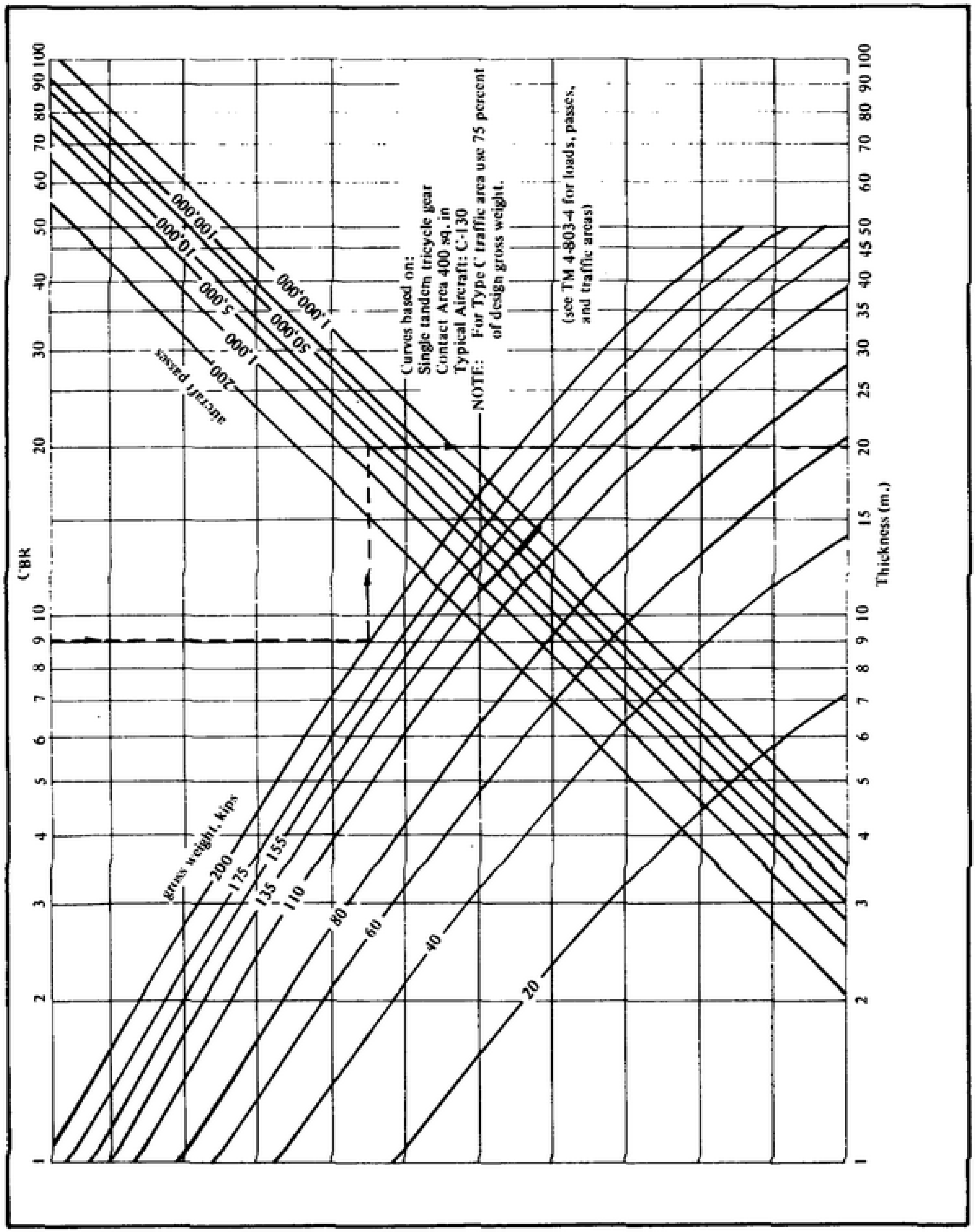

FIGURE 16. FLEXIBLE PAVEMENT DESIGN CURVES, ARMY CLASS III AIRFIELD, TYPES B AND C TRAFFIC AREAS

Problem #1: T/O Airfield Design

Design a support area, fully operational, tactical airfield capable of handling F-4C traffic. Design the Type C traffic area only. The following materials are available:

Surface: Asphalt concrete pavement
Surface treatment
Base: Sand shell
Subbase: Borrow material, GP, maximum size = 1-1/2", CBR = 0, 40% passes the #10 sieve, 4% passes the #200 sieve, LL = 20, PI = 4.
Select: None
Subgrade: ML, PI = 5, CBR = 4.

Solution:

Step 1 - Check the materials.

(1) The base material has a CBR of 80 (Table 7-2).
(2) The borrow material meets the criteria for a CBR 50 (Table 12)

Step 2 - Determine the aircraft characteristics (Table 13-10).

For an F-4C:

Design gear load	-	26.0 kips
Design curve	-	D-27
Pavement	-	3-1/2"
Base	-	6" minimum

Step 3 - Determine the cover requirements (Fig. D-27).

Material	Cover Required
4	19.5"
50	4.6"

Step 4 - Determine the thickness design.

Surface	3-1/2" asphalt concrete	
Base	6" CBR 80	4.0" min; 19.5" min
Subbase	10" CBR 50 (19.5" – 6" – 3.5" = 10")	
	CBR 4	

Step 5 - Add compaction, and draw the final design profile

3-1/2" asphalt concrete
6" CBR 80 100% CE55
10" CBR 50 100% CE55
CBR 4 Subgrade 95% CE55 (cohesionless)

PRACTICE EXERCISE FOR LESSON 2

Instructions

Check your understanding of Lesson 2 by completing the practice exercise. There is only one correct answer to each question. Try to answer all of the questions without referring to the lesson materials.

When you have completed all of the questions, turn the page and check your answers against the correct responses. Each correct response is referenced to specific portions of the lesson material so that you can review any questions you have missed or do not understand, before continuing to the next lesson.

1. What design aircraft will use a rear area, Tactical-type airfield?
   a. C-141A
   b. C-4C
   c. OV-l
   d. C-130

2. What Airfield Classification has an anticipated design life of two weeks?
   a. non-operational
   b. full operational
   c. minimum operational
   d. emergency

3. What type traffic area of a theater of operations airfield is the apron?
   a. A
   b. B
   c. C
   d. D

4. What is the minimum base thickness of an Air Force airfield?
   a. 2 inches
   b. 4 inches
   c. 6 inches
   d. 8 inches

5. What is the minimum pavement thickness for a rear area airfield with a 100 CBR base used by a C-5A aircraft?
   a. 2 inches
   b. 3 inches
   c. 3.5 inches
   d. 4.5 inches

6. Design a minimum operational, medium lift Air Force airfield, capable of handling C-130E aircraft. Design the Type B traffic area only. The following materials are available:

Practice Exercise for Lesson 2

Surface	-	Asphalt concrete pavement Surface treatment
Base	-	Soil cement
Subbase	-	GP, CBR = 47, Max size = 3/4", 47% passes the #10 sieve, 4% passes the #200 sieve, LL = 8, PI = 3.
Select	-	SC. CBR = 8, Max Size = 3/8", 82% passes the #10 sieve, 18% passes the #200 sieve, LL = 28, PI = 11.
Subgrade	-	CH, PI = 15, CBR = 4.

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PRACTICE EXERCISE ANSWERS

Lesson 2		**Learning Event**
1.	b	1
2.	d	1
3.	b	1
4.	c	2
5.	a	2 (appendix table 13-10)

6. Solution:

Step 1 - Check the materials.

(1) The base material has a CBR of 80 (Table 4).
(2) The borrow material meets the CBR 50 criteria of Table 12 for all values. The design CBR = 47.
(3) The select materials meets the criteria also. The design CBR = 8.

Step 2 - Determine aircraft characteristics (Table 13-10).

For a C-130E

Design gear load	-	83.8 kips
Design curve	-	D-29
Pavement	-	2-1/2" asphalt concrete
Base	-	6" minimum

Step 3 - Determine the cover requirements (Fig. D-29).

Material	Cover Required
CBR 4	26"
CBR 8	17"
CBR 47	4.3" rounded up to 5"

Step 4 - Determine the thickness design.

Surface	2-1/2" asphalt concrete	
Base	6" CBR 80	5" min
Subbase	8" CBR 47 (17" – 6" – 2-1/2" = 7-1/2" rounded up to 8")	17" min
Select	10" CBR 8 (26" – 8" – 2-1/2" = 9-1/2" rounded up to 10")	26" min
Subgrade	CBR 4	

Step 5 - Add compaction, draw the final design profile.

2-1/2" asphalt concrete
6" CBR 80 100% CE55
8" CBR 47 100% CE55
10" CBR 8 90% CE55
CBR 4 Subgrade 90% CE55 (cohesive)

Lesson 3
DESIGN FOR FROST CONDITIONS

TASK: Design Flexible Pavement for Frost Conditions.

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by responding correctly to 75% of the examination questions.

CREDIT HOURS: 2

REFERENCES

TM 5-330
TM 5-818-2

INTRODUCTION

In many areas where flexible pavements are placed, the effects of frost must be considered in the design. As an engineer officer you will have to determine what conditions require frost protection, choose the design method for dealing with frost, check construction for frost protection and generally compensate for the effects of frost. Frost affects most of the elements you have learned to deal with in previous lessons on flexible pavement.

Learning Event 1
CONDITIONS NECESSARY FOR FROST ACTION

INTRODUCTION

One year has colder temperatures than another year. When you design you must do it to withstand the coldest years. Sometimes you will have good records of the temperatures for previous years, sometimes the records will not be so good. You have to consider temperature and other conditions that make the situation susceptible to frost.

Terms Related to Temperature.

Average daily temperature. The average of the maximum and minimum temperatures for one day, or the average of several temperature readings taken at equal time intervals, generally hourly, during one day.

Mean daily temperature. The mean of the average daily temperatures for a given day in each of several years.

Degree-days. The Fahrenheit degree-days for any one day equal the difference between the average daily air temperature and 32°F. The degree-days are negative when the average daily temperature is below 32°F (freezing degree-days) and positive when above (thawing degree-days). Figure 17 shows curves obtained by plotting cumulative degree-days against time.

Freezing index. The number of degree-days between the highest and lowest points on a curve of cumulative degree-days versus time for one freezing season. It is used as a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperature approximately 4.5 feet above the ground is commonly designated as the air-freezing index, while that determined for temperatures immediately below a surface is known as the surface freezing index.

Design freezing index. The average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, the air freezing index for the coldest winter in the latest 10-year period may be used. To avoid the necessity for adopting a new and only slightly different freezing index each year, the design freezing index at a site with continuing construction need not be changed more than once in 5 years unless the more recent temperature records indicate a significant change in thickness design requirements for frost. The design freezing index is illustrated in Figure 17.

Mean freezing index. The freezing index is determined on the basis of mean temperatures. The period of record over which temperatures are averaged is usually a minimum of 10 years, and preferably 30, and should be the latest available. The mean freezing index is illustrated in Figure 17.

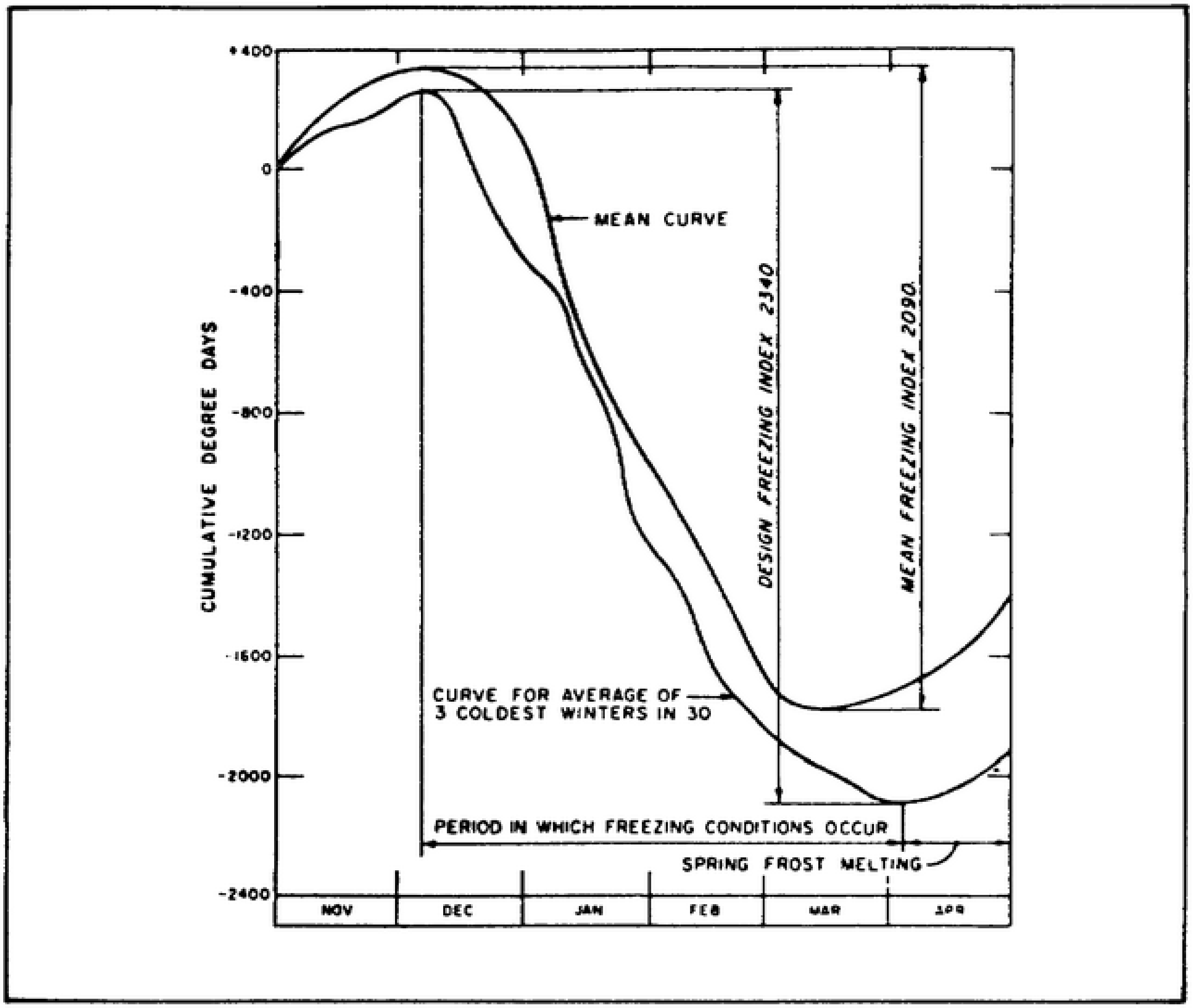


FIGURE 17. DETERMINATION OF FREEZING INDEX

Frost Susceptible Soil

To a large extent, the size of voids in a soil determines its susceptibility to frost. Most inorganic soil. containing three percent or more grains finer than 0.02mm in diameter by weight are frost susceptible for pavement design purposes. Gravels, well graded sands, and silty sands which contain 1-1/2 to 3 percent grains finer by weight than the 0.02mm size should be considered possibly frost susceptible and should be subjected to a standard laboratory test. Sandy soils with as much as ten percent of their grains finer than 0.02mm by weight may not be frost susceptible, but their tendency to be imbedded with other soils makes it impractical to consider them separately.

Frost susceptible soils are susceptible to a process called ice segregation. The <u>ice segregation</u> process occurs as follows: Water in very small void spaces remains liquid below the normal freezing temperature of water. A strong

attraction exists between this supercooled water and ice crystals that form in larger voids. The supercooled water flows to the ice crystals and solidifies on contact. The ice crystals grow and form an ice lens (Figure 18). The lens grows until ice formations at a lower level elevation cut off the source of water or until the temperature of the soil just below the surface of the ice formation rises above the normal freezing point.

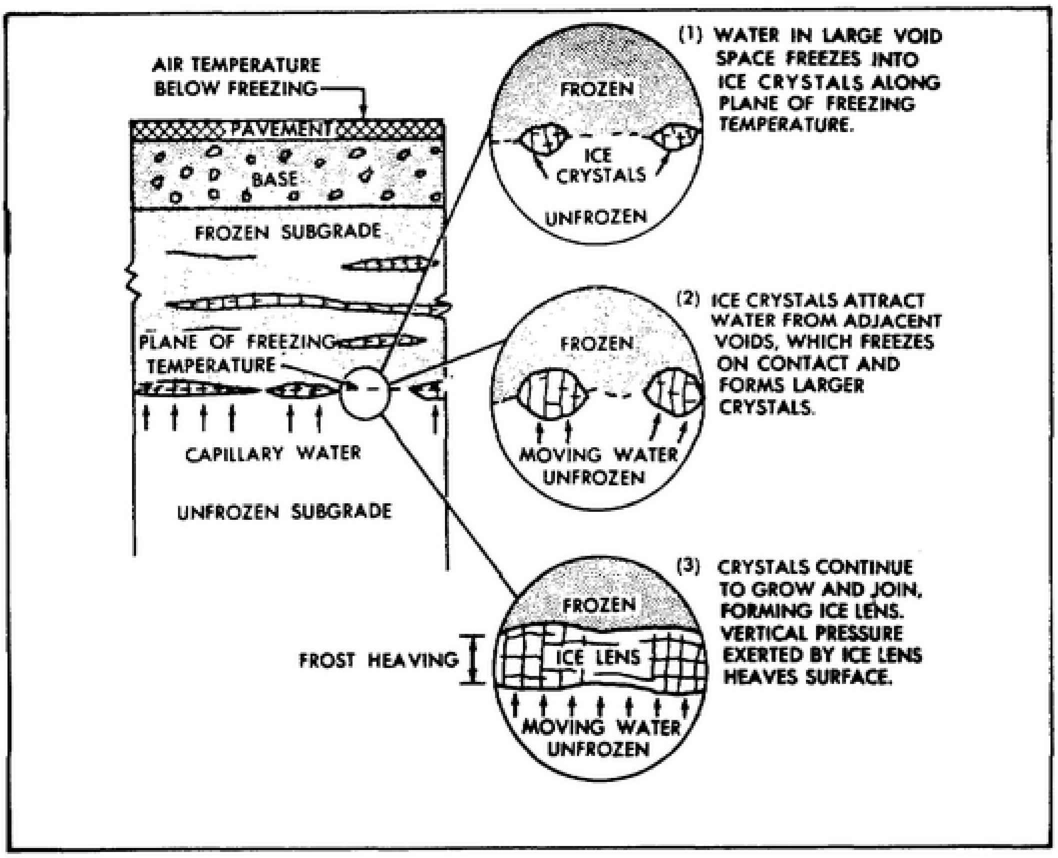


FIGURE 18. FORMATION OF ICE LENSES AT FROST LINE

Water

For ice segregation to occur (in frost susceptible soil) a source of water must be available. The water may come from the underlying ground, the water table, infiltration, an aquifer, or the water held within voids of fine-grained soils (Figure 19).

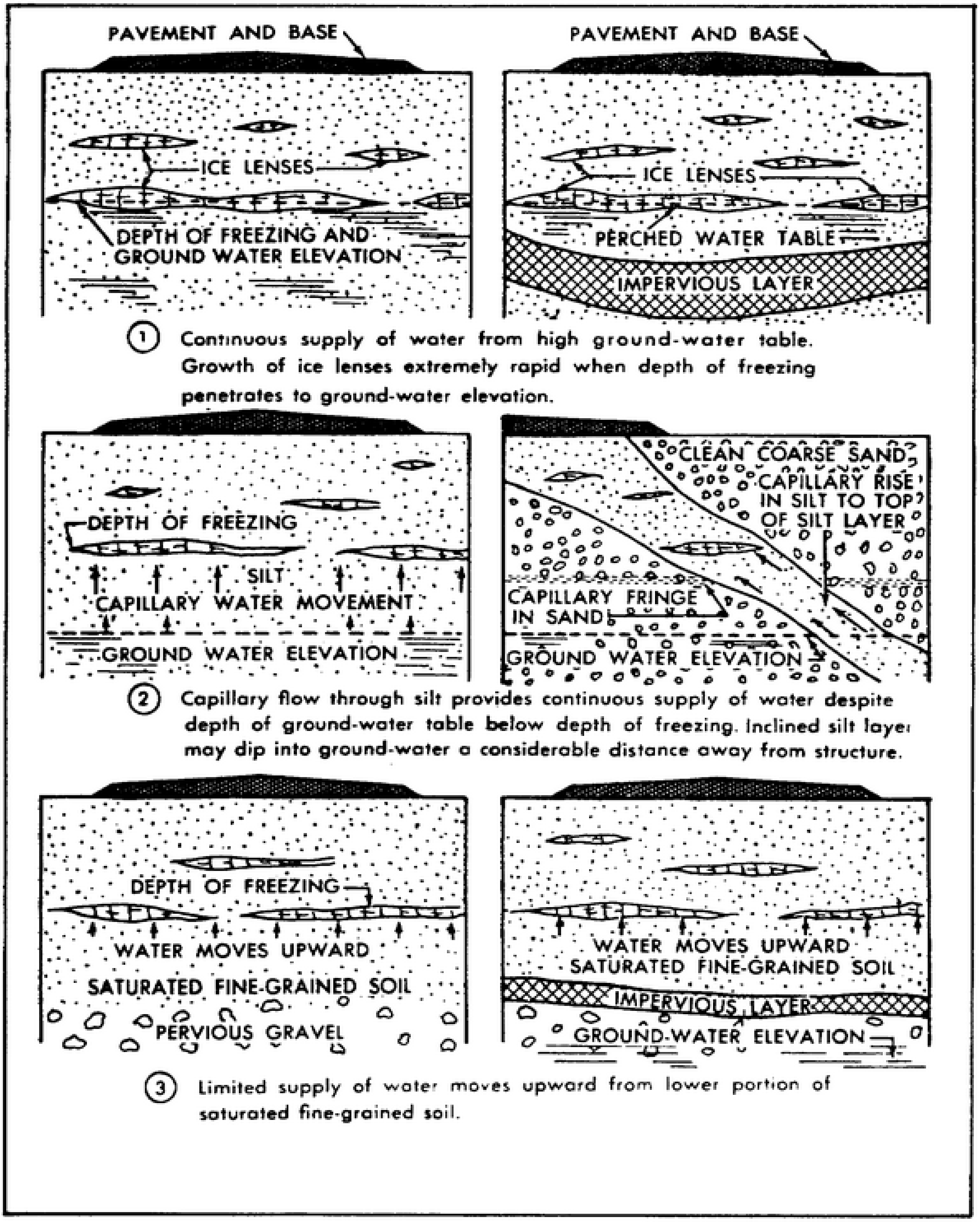


FIGURE 19. SOURCES OF WATER WHICH FEED GROWING ICE LENSES CAUSING FROST ACTION

Frost Boil

The breaking of a localized section of pavement under traffic with ejection of subgrade soil in a soft and soupy condition is called frost boil. It is caused by the melting of segregated ice.

Pavement Pumping

Pavement pumping is a problem after free water has collected under the pavement. Water and soil is ejected through joints, cracks, and along the edges of pavement when the slab is pressed down by heavy axle loads.

Effect of Frost Action on Pavement Surface

The most obvious surface effect is random cracking and roughness as the result of differential frost heave. For airfield pavements, it is essential that uncontrolled cracking be reduced to a minimum because the resulting debris may damage jet aircraft and engines.

Learning Event 2
DETRIMENTAL EFFECT AND PREVENTION OF FROST ACTION

You will need to recognize the visible effects of frost action and their causes in order to analyze what actions to take to correct these detrimental effects.

Heaving

Frost heave is indicated by the rising of the pavement. It is visible evidence that ice lenses have formed in the subgrade, in base materials, or in both. Uniform heave is the raising of adjacent areas of pavement surface by approximately equal amounts. This is associated with a fairly uniform stripping or fill depth, uniform ground water depth or horizontally uniform soil characteristics. Non-uniform heave may occur where subgrades vary between frost susceptible and non-frost susceptible soils, at abrupt transitions from cut to fill, or where excavations cut into water bearing strata. They may also occur where utility cuts have been placed through the pavement. When interruptions in pavement uniformity cannot be avoided, the best design solution is to use sufficient thickness of non-frost susceptible base to prevent frost heaving.

Thawing and Reduction in Pavement Support Capacity

In areas where ice segregation occurs, the load-supporting capacity of the pavement decreases during frost melting periods (especially in early spring). The melting of ice from the surface cannot drain through the still frozen soil below. Excess moisture from the wet and softened subgrade soil moves upward into the base course and then laterally to the nearest drain (Figure 20). If drainage is inadequate, the base course becomes saturated and its bearing capacity is substantially reduced. If there is subsequent frost action, there is accelerated deterioration.

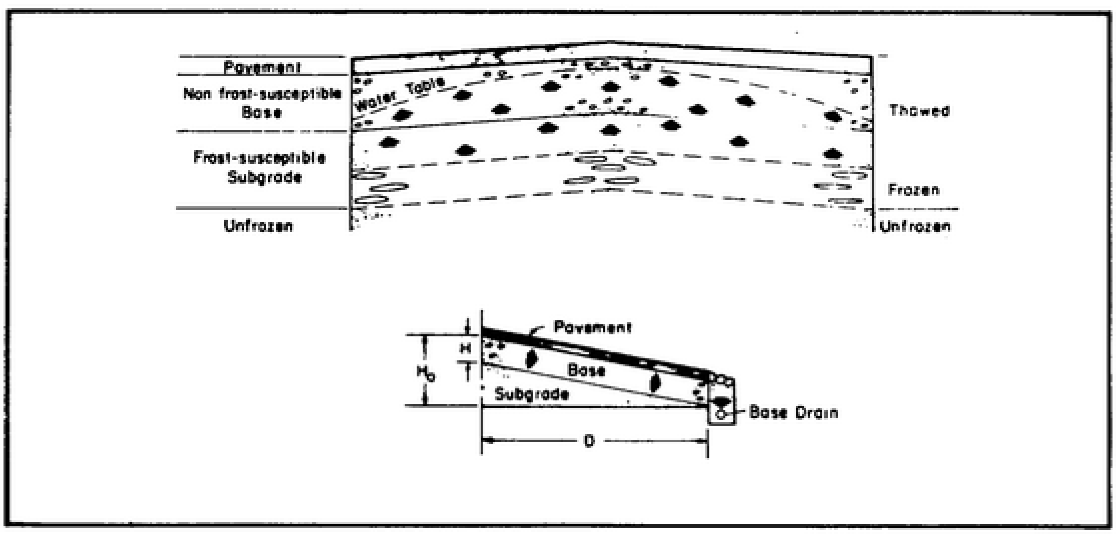


FIGURE 20. MOISTURE MOVEMENT UPWARD INTO BASE COURSE DURING THAW

Subgrade Frost Groups

Soils are classified into four groups for frost design purposes. These classifications are described in Table 13, Frost Design Soil Classification.

TABLE 13. FROST DESIGN SOIL CLASSIFICATION

Frost Group		Percentage Finer than 0.02mm by Weight	Typical Soil Types Under Unified Soil Classification System
F1	Gravelly Soils	3 to 10	GW, GP, GW-GM, GP-GM
F2	Gravelly Soils	10 to 20	GM, GW-GM, GP-GM
	Sands	3 to 15	SW, GP, SM, SW-SM, SP-SM
F3	Gravelly Soils	Over 20	GM, GC
	Sands (except very fine silty sands)	Over 15	SM, SC
	Clays	---	CL, CH
F4	All silts	---	ML, MH
	Very Fine Silty Sands	0 to 15	SM
	Clays, PI $<$ 12	---	CL, CL-ML
	Varied Clays and Other Fine-grained Banded Sediments	---	CL and ML; CL, ML and SM; GL, CH, and ML; CL, CH, ML, and SM

Material with optimal frost protection characteristics will not always be available for each project. Examine and test available materials and determine into which group they fall. Having determined the subgrade frost group category of material available, use the frost group to enter into design calculations of thickness required. Calculations for required thickness for the category of material will be covered later in the lesson.

Learning Event 3
FROST PROTECTION

Complete frost protection is provided when the thickness of non-frost susceptible base and pavement is sufficient to protect the subgrade on even the coldest days. In other words, the maximum depth of frost penetration (on the coldest day) is less than the depth of non-frost susceptible materials in the pavement.

Depth of Frost Penetration

The depth to which freezing temperature will penetrate below the surface of a pavement kept cleared of snow and ice depends principally on the magnitude and duration of below-freezing air temperatures, on the properties of the underlying materials, and on the amount of water which becomes frozen. The curves in Figures 21 and 22 may be used to estimate values of frost penetration beneath paved areas kept free of snow and ice. They have been computed for an assumed 12-in. thick rigid pavement, using the modified Berggren formula and correction factors derived by comparison of theoretical results with field measurements under different conditions. The curves yield maximum depths to which the 32°F temperature will penetrate from the top of the pavement under total winter freezing index values in indefinitely deep, homogeneous materials for the indicated density and moisture content properties. Where individual analysis is desired or unusual conditions make special computation desirable, the modified Berggren formula may be applied (see Notes, Figure 21). Neither this formula nor the curves in Figures 21 and 22 are applicable for determining transient penetration depths under partial freezing index values. Values obtained by use of Figures 21 and 22 should be verified whenever possible by observations in the locality under consideration.

Preventive Actions

There are several means of dealing with frost action. In reality, some are more practical than others. You should know the options and recognize which option is most likely to be the better alternative in most situations.

There are four preventive actions that can be taken:

- Insulate the subgrade
- Remove frost susceptible material
- Prevent capillary movement into the freezing zone
- Increase the distance from top of subgrade to ground water level.

The preventive action of increasing the distance from the top of the subgrade to ground water level is accomplished by increasing the thickness of the flexible pavement. Determining what thickness is needed to prevent or control the detrimental effects of frost action will be discussed in other parts of this lesson.

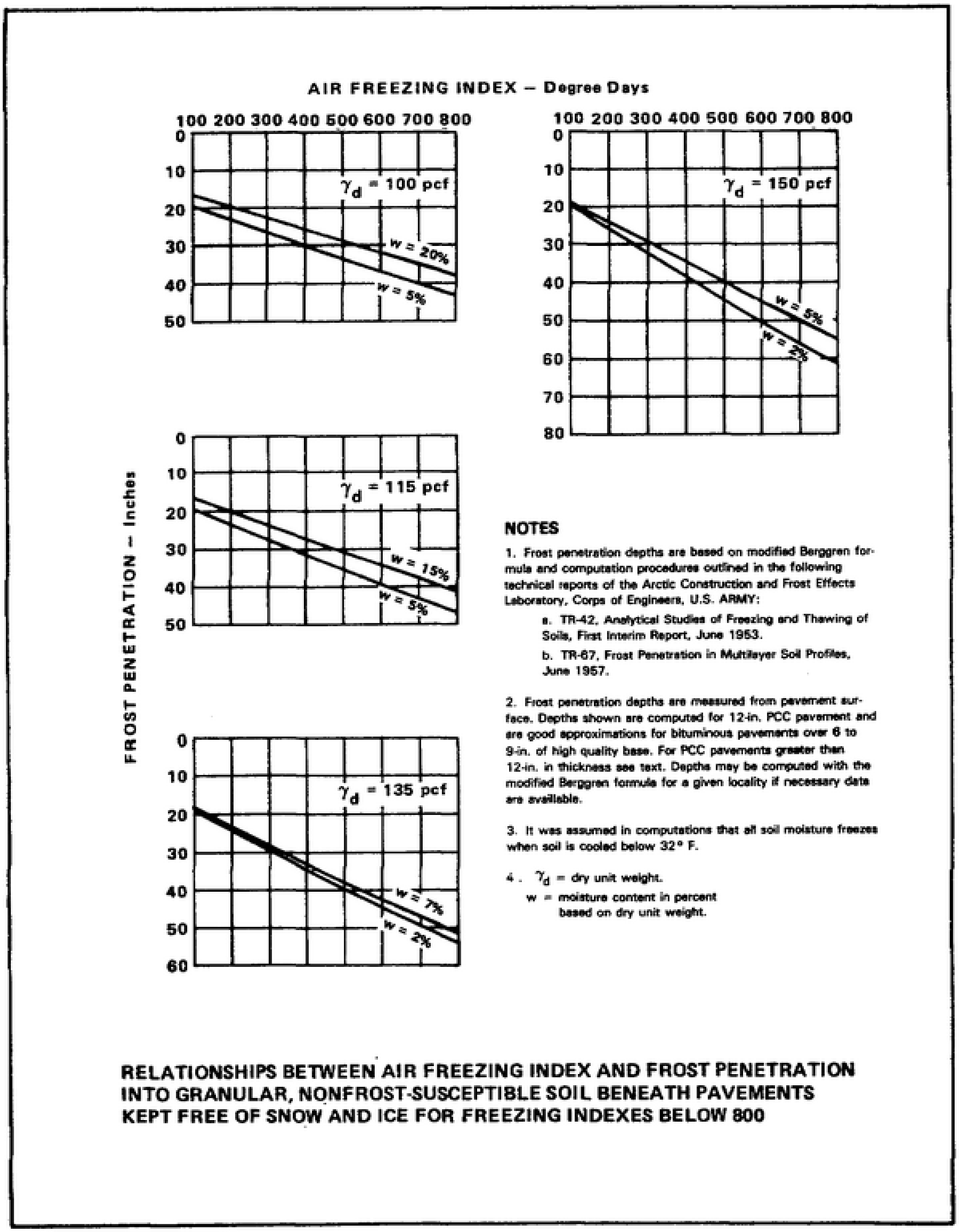
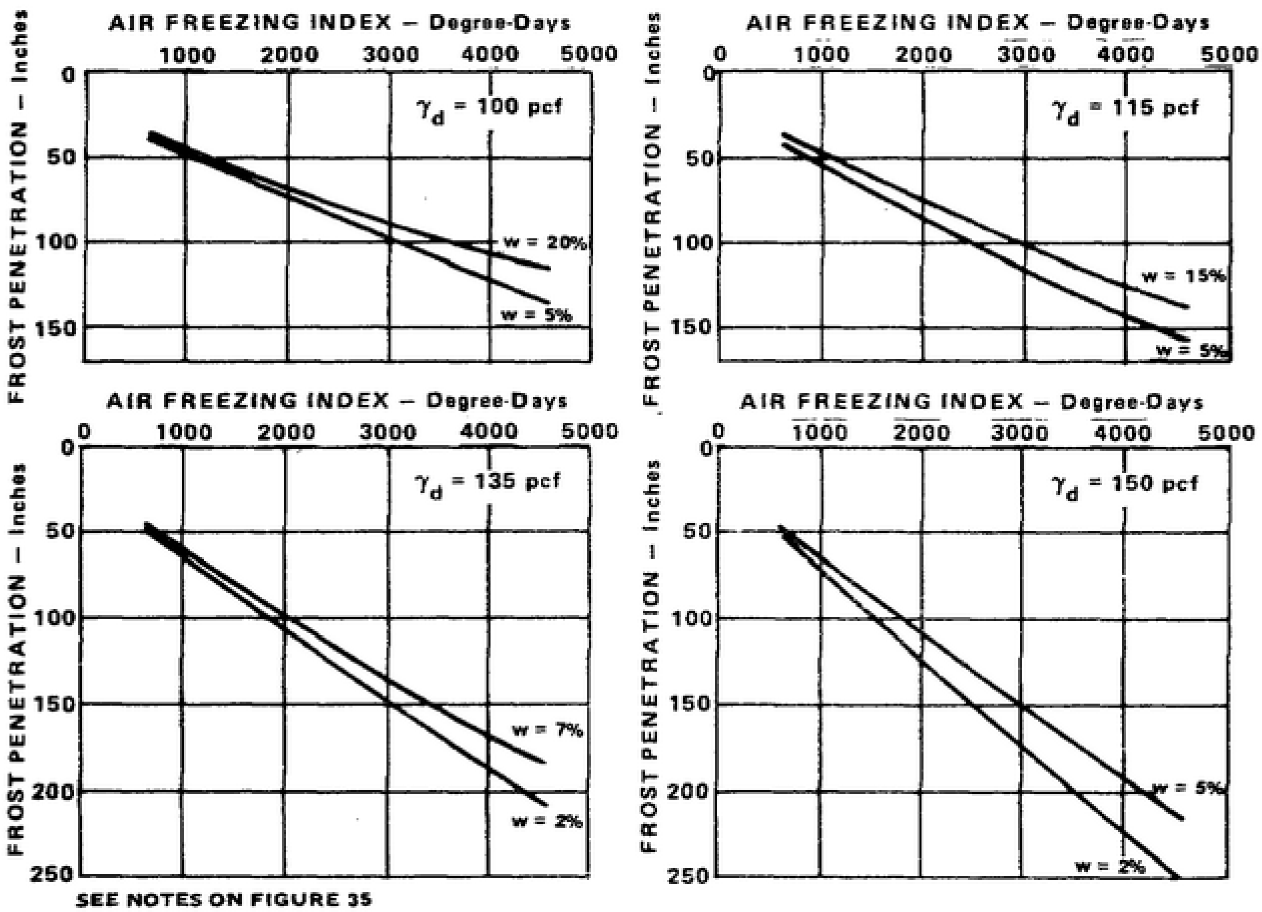


FIGURE 21. CURVES FOR EVALUATING VALUES OF FROST PENETRATION



RELATIONSHIPS BETWEEN AIR FREEZING INDEX AND FROST PENETRATION INTO GRANULAR, NONFROST-SUSCEPTIBLE SOIL BENEATH PAVEMENTS KEPT FREE OF SNOW AND ICE FOR FREEZING INDEXES BELOW 800

FIGURE 22. CURVES FOR EVALUATING VALUES OF FROST PENETRATION

In order to further insulate the subgrade, to allow water to drain out of the flexible pavement structure, and to prevent capillary movement of water up from the subgrade, a 4" layer of well draining material is placed immediately above the subgrade. This "frost filter" is normally constructed of a graded sand.

Lesson 3/Learning Event 3

Design of Pavement for Frost Action

The design of pavements in frost areas can be based on either of two basic concepts: control of surface deformation resulting from frost action, or provision of adequate bearing capacity during the most critical climatic period. Under the first concept, sufficient combined thickness of pavement and nonfrost-susceptible base must be provided to eliminate or limit to an acceptable amount, subgrade frost penetration and effect thereof. Under the second concept, the amount of heave which will result is neglected and design is based solely on the anticipated reduced strength of the subgrade during the frost-melting period. The following three design methods have been derived from these concepts:

- Complete Protection Method
- Limited Subgrade Frost Penetration Method
- Reduced Subgrade Strength Method

The first step in determination of design thickness is to select the appropriate design method or methods from Table 13, which summarizes the conditions for which each of the above methods is applicable. The degree of horizontal variability of subgrade soil and moisture conditions may be classified into one of four categories: <u>Uniform</u>, <u>slightly variable</u>, <u>variable</u>, or <u>extremely variable</u>. Definitions of these adjective categories are given under the respective adjective headings in Table 13. The distinctions are purely qualitative. Selection of the adjective category involves the exercise of judgment; it must be based on careful analysis of past performance of pavement in the area and very thorough study of the data revealed by the site explorations. An airfield may fall entirely into one adjective category, or it may have to be divided into a number of areas for separate design consideration. Once an adjective category has been chosen, the design approaches which are applicable may be ascertained from Table 13.

It should be noted that the requirement for sufficient bearing capacity during the normal period (summer and fall), as determined by temperate design, takes precedence over the frost design criteria if it requires greater combined thickness than that obtained by the frost design methods.

Thicknesses of pavement surfacing and high quality base are not changed during the frost design. Thickness adjustments required to attain the combined thicknesses determined for frost design of the controlling pavement types will be made in the lower base materials provided for frost design.

Reduced Subgrade Strength.

Thickness design may also be based on the reduction in strength of the subgrade which occurs during thawing of soils which have been affected by frost action. This design method normally permits less thickness of pavement and base than that needed for limited subgrade frost penetration. The method may be used for flexible pavements on F1, F2, and F3 soils when the subgrade is horizontally uniform (or slightly variable for flexible pavements) such that significant or objectionable differential heaving and resultant cracking of pavements will not occur. The method may also be used for flexible type pavements on F1 through F4, horizontally variable subgrades when the pavements are of a minor-slow-speed, and non-critical character in which heave and its effects can be tolerated. When the reduced subgrade strength method is used for F4 subgrade soils, the combined pavement and base thicknesses should be determined using the design curves for F3 soils in Figures 13-15 through 13-21 in the Appendix. When a thickness determined by the reduced subgrade strength method exceeds that determined for limited subgrade frost penetration or for complete protection, the applicable smaller value shall be used, provided it is at least equal to the thickness required for non-frost conditions.

In situations where use of the reduced subgrade strength method might result in objectionable surface roughness or pavement cracking caused by frost heave, but use of the limited subgrade frost penetration design method is not considered necessary, intermediate design thicknesses may be used, as necessary, to prevent objectionable heaving, provided justification is offered on basis of frost heaving experience developed from existing airfield and highway pavements where climatic and soil conditions are comparable.

Flexible pavements. In the reduced subgrade strength method of design, the curves in Figures 13-15 through 13-21 in the Appendix should be used to determine the combined thickness of flexible pavement required for aircraft wheel loads and wheel assemblies. Figure 13-22 should be used for highway design. The curves for highways require greater combined thicknesses than the curves for equivalent single-wheel aircraft loadings because of the higher frequency of load applications. General field data and experience indicate that on the relatively narrow embankments of highways, reduction in strength of subgrades during frost melting may be less in substantial fills than in cuts because of better drainage conditions and less intense ice segregation. If local field data and experience show this to be the case, then a reduction in combined thickness of pavement and base of up to 10 percent may be permitted for highways on substantial fills. In no case shall the combined thickness of pavement and nonfrost-susceptible base be less than 9 inches where frost action is a consideration.

Learning Event 4
COMPACTION REQUIREMENTS

The subgrade must be compacted for the same frost conditions as for temperate conditions.

There are compaction requirements for airfields and highways. The strength versus settlement criteria should be compared for fill and then cut sections. The compaction design is then superimposed onto the thickness design for fill and cut sections. Before compaction requirements are considered all of the design methods are carried out.

Superimpose Compaction Requirements

After you have arrived at a design for frost action conditions and determined compaction requirements, you must superimpose compaction onto the thickness for final design.

Compaction for frost action conditions must be incorporated into the regular temperate climate design for final design. It is only after a method has been selected and used for design that compaction requirements are superimposed to arrive at a final design (Figure 24).

Examples of Flexible Pavement Design

Example. Design a minimum operational flexible pavement for a C-121G cargo aircraft having a design load of 69,400 pounds, twin tricycle gear configuration, and a tire contact area of 262 square inches for the following conditions:

Subgrade. Uniform clay (CL), plasticity index 18, CBR = 8 (normal period) and an average water content of 25 percent. It is assumed that the subgrade soil produces uniform heave.

Base CBR = 80. The highest ground water table is recorded to be 4 feet below the surface of the natural subgrade. Soil type is GW, well-graded gravel.

Reduced subgrade strength design (Figure 23**).** The subgrade soil is a CL having uniform heave characteristics and a plasticity index of 18, classifying the soil group F3. Using Figure 13-19 and a design load of 69,400 pounds, it is found that 44 inches combined thickness of pavement and nonfrost-susceptible base and subbase course is required for the design aircraft over the weakened subgrade soil. A 4-inch filter blanket must be placed as an integral part of the base or subbase course, at the transition between the frost-susceptible subgrade soil and the non-frost-susceptible base or subbase soil. Use a 10 percent reduction in traffic area "C."

Final pavement design. The frost design and the "temperate climate design" is then combined as shown in Figure 24.

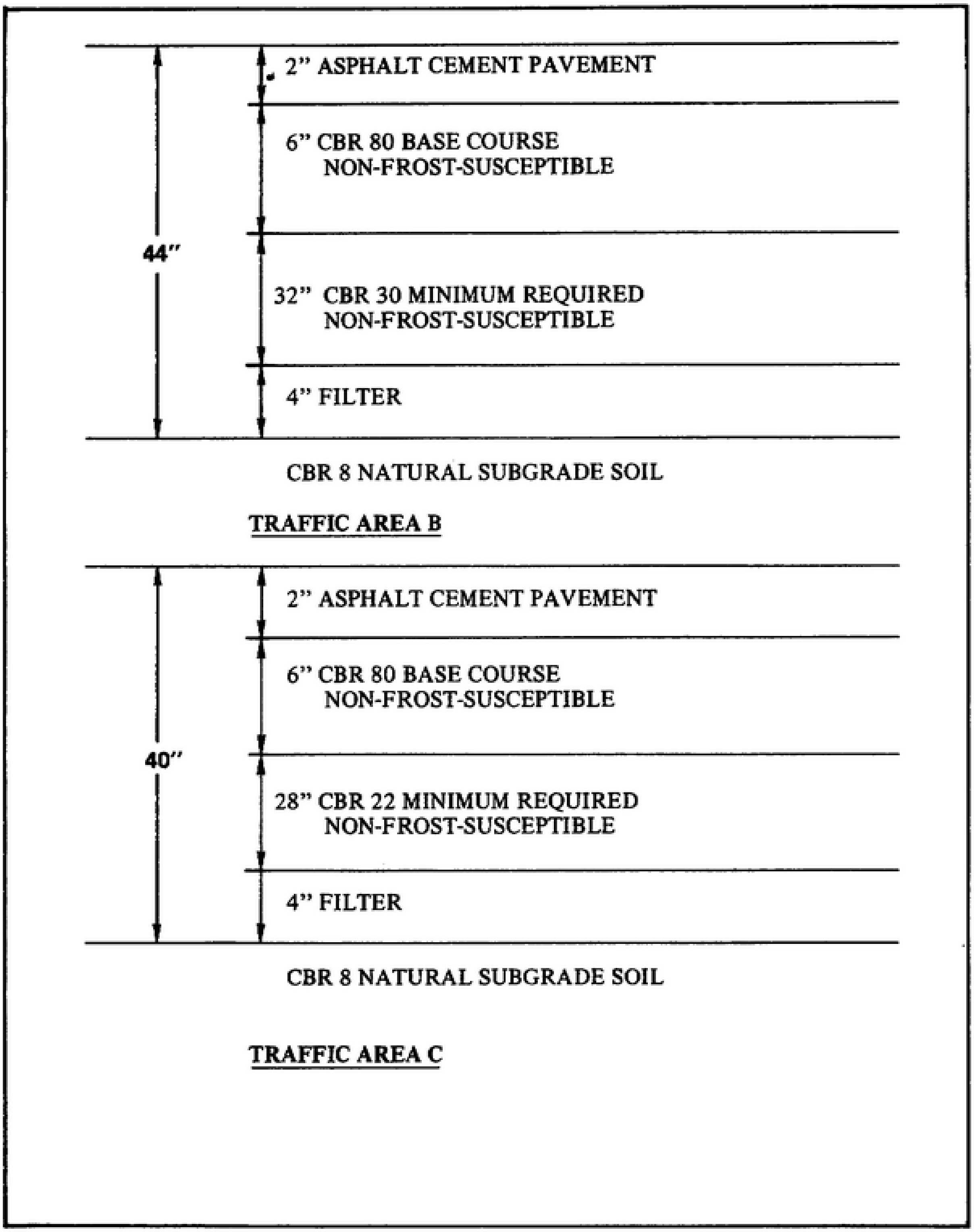


FIGURE 23. REDUCED SUBGRADE STRENGTH DESIGN RAW DESIGN

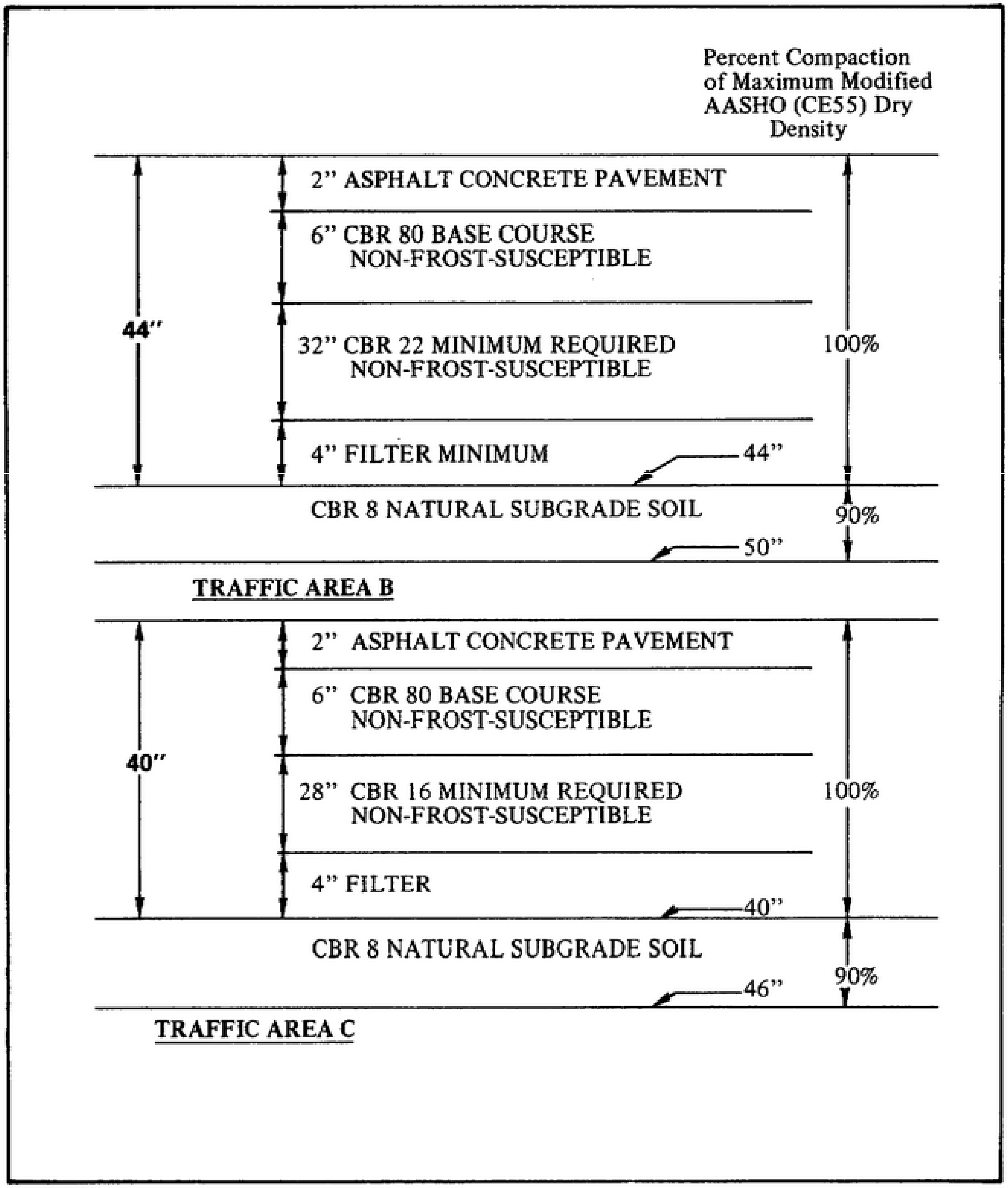


FIGURE 24. FINAL PAVEMENT DESIGN

Problem #3: Frost Design

Design the flexible pavement for frost for T/O airfield Problem #1. Assume that the subbase material is NOT frost susceptible. The F-4C has a single wheel landing gear with 100 in^2 of contact area.

Solution

Step 1 - Determine the total pavement thickness.

The subgrade is classified as an F-4 because it is a silt. Use the curve for F-3, but expect "objectionable surface roughness."

Using a 26.0 kip gear load, the total pavement thickness is 28" (Fig. 13-15) for Type B. Reduce by 10% for a Type C (25.2").

Step 2 - Determine the thickness design.

Surface	3½” asphalt concrete	25.2” min
Base	6” CBR 80	
Subbase	12” CBR 50 (25.2” –3½” –6” –4” = 11.7” rounded up to 12”)	
Filter	4” frost filter	
Subgrade	CBR 4	

Step 3 - Add compaction requirements and draw the final design profile as for temperate design.

PRACTICE EXERCISE FOR LESSON 3

Instructions

Check your understanding of Lesson 3 by completing the practice exercise. There is only one correct answer to each question. Try to answer all of the questions without referring to the lesson material.

When you have completed all of the questions, turn the page and check your answers against the correct response. Each correct response is referenced to specific portions of the lesson material so that you can review any questions you have missed or do not understand.

1. The ejection of water and soils through cracks caused by heavy axle loads, after free water has collected under the pavement, is called

   a. frost boil.
   b. frost action.
   c. pavement pumping.
   d. soft and soupy conditions.

2. Without exception, the thickness of pavement and non-frost-susceptible base can be no less than

   a. 3 inches.
   b. 6 inches.
   c. 7 inches.
   d. 9 inches.

3. What will be the combined thickness of the pavement and base using the Reduced Subgrade Strength Method, using the following information:

Given:	Design wheel load	=	25,000 lbs
	Traffic Area	=	Type B
	Subgrade Material	=	Horizontally uniform clay (CL) Plasticity Index, 18 Water Content, 25% (avg) Normal Period, CBR 8
	Base		CBR 100 (Normal period, high quality graded crushed aggregate) CBR 50 (Remainder of base non-frost-susceptible sandy gravel (GW) Any water content after drainage 5% Highest ground water 3 feet below the surface or subgrade.

a. 33 inches.
b. 28 inches.
c. 20 inches.
d. 19 inches.

4. Design the flexible pavement for frost for T/O airfield Problem #2. Assume that the subbase material is NOT frost susceptible but that the select material is (18% passes the #200 sieve). The C-130E has a single-tandem landing gear with 400 in^2 in each wheel.

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ANSWER SHEET TO PRACTICE EXERCISE

Lesson 4	Learning Event
1. c	2
2. d	4
3. b	4

4. Solution:

<u>Step 1</u> - Determine the total pavement thickness.

The subgrade is classified as F-3 because the PI is greater (>) than 12. Using an 83.8 gear load, the total pavement thickness for a Type B area is 44" (Figure 13-21).

<u>Step 2</u> - Determine the thickness design.

2½" asphalt concrete

6" CBR 80

32" CBR 47 (44" – 2½" – 6" – 4" = 31.5" rounded up to 32")

4" frost filter

44" min

<u>Step 3</u> - Add compaction requirements and draw the final design profile as for temperate design.